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TYPES OF CLIMATIC ZONES IN THE POST-PROTEROZOIC HISTORY OF THE EARTH AND THEIR SIGNIFICANCE IN GEOLOGY[1]

by

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The problem of climatic zonation of past geologic epochs is one of the most interesting, and the most difficult, in geology. Attempts at its solution go as far back as the second half of the nineteenth century and are still underway. They have become particularly intensive in the last 15 years. Despite the great number of studies completed, it cannot be said that even the main outline of this problem has been cleared up, both in terms of subject matter and method of study. This brings us back, again and again, to an analysis of the problem.

Having been studying the climatic zonation of past geologic epochs since 1945, the author has achieved certain new results of a general nature. They are the subject of this paper.

But first a few words on the principles and methods of paleoclimatic study in general.

1. PRINCIPLES OF RECONSTRUCTION OF PAST CLIMATIC ZONES

Up to now, climatic reconstructions have been based on two kinds of data: on the organic world of the past and on the character of sediments. In so doing, the authors usually did not estimate the relative value of data of the first and second groups, and their conclusions were often based solely on paleontologic material. As a matter fact, it is quite obvious that the value of organic remains and lithologic features is substantially different.

When a student deals with a moraine, especially one resting on an abraded and polished floor marked with glacial striations, his conclusion on the presence here of a past glaciation is unequivocal and unquestionable because no other process produces such a combination of lithologic features. By the same token, when a lithologist comes across gypsum or salts (rock salt, K-salts) in a section, his inference of past arid conditions at that place is also unequivocal and incontrovertible. No less demonstrative of humid conditions is the presence of a clean-cut chemically weathered crust with kaolin, bauxite, iron and manganese ores, and coal, because they all are known to originate under humid conditions only. The distinction of the above-named lithologic data is that they afford definite and incontrovertible conclusions; for that reason, they can be confidently used in a reconstruction of paleoclimates.

The situation is altogether different for organic remains, both terrestrial and especially marine. The inference of west European Eocene vegetation belonging to a tropical zone is based on its general similarity in composition and nature to the modern tropical fauna of southwestern Asia. At first glance, such a conclusion appears to be well founded; as a matter of fact, however, it is not so. A similarity in floras suggests a similarity in the ecologic conditions of growth, such as annual temperatures and humidity. Such conditions, however, do not have to be necessarily realized in the same climatic belt. At the present time, high temperatures and the humidity of southeastern Asia fall into a tropical belt. In the Eocene, however, the same temperature and humidity could have prevailed locally substantially to the north, in subtropics, as indeed was the case in the Eocene of western Europe.

Another example: annual rings occur in trees of both the temperate-humid belt and arid subtropics. In the first, they reflect an alternation of cold and warm seasons; in the second, of arid and humid. It is impossible to tell apart dry and humid climates, with certainty, by wood structure. The situation is even more complicated for marine organisms. Coral colonies, beloved by paleoclimatologists, dwell in seas of both the arid (Red Sea) and humid (Indian Ocean, West Pacific) provinces. The same is true for fusulinids, lepidocyclinas, nummulites, archaeocyathids, and other lime-secreting organisms of the geologic past. All these forms are warmth-loving, of course, but it is quite impossible to distinguish by their presence humid tropical conditions from arid or humid subtropical.

[1] Tipy klimaticheskoy zonal'nosti v posleproterozoyskoy istorii zemli i ikh znacheniye dlya geologii.

Thus, unlike lithologic data, paleontologic material does not afford a definite solution to the problem of climatic conditions; its simplified correlation with the present organic world may lead (and often does) to gross errors.

Consequently, in all paleoclimatic reconstructions, preference should be given to lithologic rather than paleontologic features. It is rocks that should constitute a base for paleoclimatology, with paleontologic material only as a supplement for pinpointing certain details of climatic conditions. A primarily lithologic basis is the first and fundamental principle of paleoclimatologic study.

However, in advocating rocks rather than organic remains as the basis for paleoclimatic reconstructions, it should be emphasized that by no means can all rocks be so used but rather a limited group of them, the so-called climate index rocks.

Such natural indexes of glacial zones are the aforementioned moraines with such peculiar bedrock features as polish, striations, etc. Indexes of a humid belt are ores of iron and manganese, bauxite, kaolin (primary, not redeposited), coal, and finally the chemically weathered crust. Indexes of dry zones are halogens: gypsum, anhydrite, fluorite and celestite, rock and K-salts. Red continental deposits can be used as indexes of an arid climate only when they are carbonate; carbonate-free redbeds, on the other hand, should be interpreted as deposits of a humid climate.

Inasmuch as climatic zones of the past, like the present ones, were characterized by fairly complex outlines, their reliable representation on a map calls for an adequate number of points representing index rocks. For that reason, comprehensive material is a prerequisite. A substitution for it of other paleontologic material is inadmissible; this is especially true for an ancient period whose climatic zonation was sharply different from the younger and the present one. Here, each new fact is of immense importance; it often substantially modifies an earlier interpretation.

The third principle of paleoclimatic reconstructions is the comprehensive character of past climates. One cannot limit himself to the reconstruction of a single zone, the arid for instance, by gathering data only from index rocks for dry conditions, as has been done by F. Lotze in his reconstruction of "salt-generating" belts. The error of his specific representations lies in the very fact that in plotting his points on a map he combined them fairly arbitrarily, not taking into consideration rocks indicative of humid climate and providing control for dry zones. As we shall see below, such control is at times helpful in reproducing very reliable, albeit complex outlines of climatic belts for individual periods of geologic history.

In interpreting the climatic zonation of past epochs, it is extremely important to distinguish with certainty a humid tropical zone from temperate northern and southern zones. This was done usually from geologic data. However, Keppen and A. Wegener proposed in 1925 a new and more reliable criterion. The substance of it is that the cause of atmospheric circulation is that a humid tropical zone is always located between the north and south arid belts, with temperate belts lying outside these zones, to the north and south of them. This principle is the guiding one, in the present study; it has been applied in all of my previous works and is taken as a basis for the present one.

Of great interest in paleoclimatic reconstructions is the equator's position corresponding to that of the earth's axis, in ancient geologic epochs. At times, the entire task of a geologist is reduced essentially to a solution of that problem, as witness the recent study by L. B. Rukhin. It should be kept firmly in mind, however, that a reconstruction of the equatorial plane and the rotational axis of the earth, with relation to the present ones, can be done only approximately, rather than precisely. The only way to find such an approximate solution is first to determine the north and south arid zones. The equator should always pass between them, with the configurations of the arid zones themselves suggesting its best median position. This principle must remain unshakable in paleoclimatic reconstructions. Its replacement by evaluations of the nature of plant assemblages or of some specific organic forms always leads to errors and often to constructions quite impossible from a climatic point of view.

Such are the principles upon which I have drawn my paleoclimatic maps.

A total of 13 maps have been constructed: Neogene, Paleogene, Late Cretaceous, Early Cretaceous, Late Jurassic, Middle and Early Jurassic, Triassic, end of Early and beginning of the Late Permian, Middle and Late Carboniferous, Early Carboniferous, Middle Devonian, Gotlandian, and Ordovician. Their correlation with one another has shown that although the outlines of paleoclimatic zones for two consecutive epochs (or periods) are never identical but rather markedly different, maps of several consecutive epochs reveal the presence of a certain general plan of zonation persisting for some time, then giving place to another. On the whole, three consecutive plans can be traced from the Ordovician to the present. Each of these three plans is recognizable on three to five maps.

It is impossible to reproduce and analyse all of these maps in a magazine article, hence I shall confine myself to three of them one for each type of zonation, selecting each time the most typical and documentally substantiated, and noting briefly those secondary variations observable on other maps of the same plan.

2. CLIMATIC ZONATION IN THE CENOZOIC AND MESOZOIC

Neogene map, Figure 1, is fundamental for an understanding of the Cenozoic and Mesozoic climatic zonation plan. We note first of all the abundance of points fixing the locations of index rocks for humid and arid conditions, and their generally close occurrence, which lends adequate certainty to the Neogene paleoclimatic zonation so established. We shall not name all of the individual localities of arid and humid deposits, which are sufficiently well represented on the map, but confine ourselves to a general survey of climatic zones.

In western North America, there is a small area indicating Neogene arid conditions, as witness the findings of fairly thick to thin rock salt and gypsum beds, in Miocene and Pliocene deposits of Nevada, California, Idaho, and Wyoming ([27], pp. 144-145). The northern limit of this province is determined by findings of Miocene bauxite in Oregon, Washington, and Montana; its southern limit lies in Guatemala and the Antilles (Jamaica, Haiti). This arid area fully coincides with the present arid province of the Great Issueless Basin, differing from the latter in details of configuration; for lack of data, we are unable to reconstruct in detail the outlines of this Neogene dry area.

According to E. Antevs [23], this arid area was non-existent in the Early Miocene; it appeared in the Middle Miocene and attained its present size in the Late Pliocene.

To the east, in the Old World, the Neogene witnessed a vast new dry province embracing southern Europe, North Africa, Arabia, and central Asia (southern U.S.S.R., western China, etc.). Its arid conditions are suggested by the presence of salt in the troughs of the Ebro, Duero, and Tajo (Spain); along the north Carpathian border (Kalush), in Upper Silesia, and in the Sandomir Mountains; south of there, halogen deposits are known from Galicia, Bukovina, Moldavia, and Walachia. Inside the Carpathian arc, thick salt and gypsum beds have been discovered in Miocene beds of Transylvania. The Italian Miocene includes gypsum and salt accumulations in the Piedmont-Ligurian trough, on the Adriatic slopes of the Apennines, in Toscany, in the vicinity of Rome, and finally in Calabria and Sicily (here, gypsum beds are up to 100 m thick, with subordinate sulfur deposits). In the Pliocene of Europe, the formation of gypsum was sharply curtailed areally, persisting only locally in Spain, Toscany, and Albania.

In Africa, Miocene gypsum occurs in Algieria, Tunisia, and northern Egypt whence they extend along the Red Sea shore as far as 24° north latitude. Gypsum beds also are widely developed on the Asian side of the Gulf of Suez, specifically on the Sinai peninsula and to the south; the salt deposits of Yemen are also Miocene in age. Contrary to the European situation, Pliocene halogen deposits of Africa are developed in almost all of the above-named regions.

In western Asia, a belt of Miocene gypsum and some halite extends from Syria across Mesopotamia, as far as the Gulf of Persia; it is of the same age as the Carpathian halogen series. Northeast of there, gypsum and salt deposits occur in Armenia, Iran (south of the Caspian), on the Krasnovodsk Plateau, at Kopet-Dag, the intermontaine trough of Tyan'-Shan' (glauberite-halite formation of V. N. Shcherbina), and in the Tarim trough. Along the northern border of the arid zone, gypsum inclusions occur in the Aral formation of the Turgay Plateau.

All these points mark a vast Neogene dry province of the Old World, surrounded by humid regions. Bordering on the arid province in Europe are the Miocene coal measures of Germany and Poland, with the Pliocene Kerch basin to the east. In Asia, its northern boundary is marked by the Sayan-front lignite deposits; the eastern boundary, by coal deposits of the Sakhalin - Vladivostok - South Japan belt and the bauxite of Indochina, Sumatra, Borneo; the southern boundary, by the vast development of lateritic crusts in South America, Equatorial Africa, India, and North Australia; it is, at least partially, Pliocene in age.

As readily seen on the map, index rocks of humid and arid conditions usually occur so close to each other that the boundaries of the arid European-African-Asian province are drawn fairly reliably and are subject to only insignificant shifting in a detailed study of individual localities. In other words, the outline and dimensions of the Old World Neogene arid province have been reconstructed with sufficient certainty. In this connection, it is particularly significant that the outline, dimension, and localization of this province in the Neogene closely correspond to those of the present dry province of the Old World. The main difference is only in Europe where Miocene arid conditions extended considerably farther north than they do now. However, that bulge was abruptly shrunk to almost nothing as early as the Pliocene when the conditions approached those of the present. Such local differences in the position of the arid zone during different (even

FIGURE 1. Climatic zonation in the Neogene

I - humid tropical zone; II - northern arid zone; III southern arid zone; IV - northern temperate zone. Humid zone: 1 - coal; 2 - bauxite; 3 - iron ore; 4 - manganese ore; 5 - weathered crust. Arid zone: 6 - minor deposits of gypsum and salts; 7 - extensive halogen deposits; 8 - redbeds with lentils of halogen rocks; 9 redbeds with carbonate material; 10 - trend of arid provinces. Glacial province: 11 - continental type glaciation; 12 - highland type glaciation. For all zones: 13 - uncertain occurrence of some type of deposits; 14 - mountain structures.

consecutive) moments of time are quite natural, being brought about by changes in relief of adjacent regions, and in no way detract from general similarity in localization and configuration of present and Neogene arid provinces.

In Asia Minor we find another example of local changes in the arid zone outlines at different moments of the Neogene. Thus coal was still being formed in the vicinity of Izmir, during the Early Miocene, denoting a humid climate in the beginning of the Miocene [15]. In the Late Miocene, on the other hand, salt and gypsum deposits were widely developed in different areas of Asia Minor (near Galis, in eastern Taurus, along the southeastern and northern edges of the Likaon block, in Paphlagonia, western Misia, and elsewhere [27]), indicating a greater aridity of the peninsula.

All these differences in detail, however, do not remove the basic fact that both Neogene arid provinces, components of the northern arid provinces, components of the northern arid zone (North American and European-African-Asian), were located at the same places as the modern ones. Inasmuch as the Atlantic was already in existence, at that time, it can be assumed that the two arid provinces were separated by a meridionally trending oceanic region with humid climate in the Neogene even as they are now.

Data on the southern arid zone are considerably more scarce. Its evidence has been established with certainty only in South America where numerous gypsum deposits are known from the topmost Miocene and Pliocene beds of Peru. No definite traces of Neogene deposits have been found in South Africa and Australia, as yet. It is important, however, that the position of a Neogene arid province in South Africa coincide exactly with the present one. Considering that in the Northern hemisphere, too, Neogene and present arid provinces coincide, it becomes clear that on the whole (down to details) the distribution of arid and adjacent humid zones in the Neogene was similar to the present one. In other words, the over-all plan of atmospheric circulation in the Neogene was the same as now, in its principal features. Hence, the inescapable conclusion that arid conditions prevailed in the same regions of South Africa and the interior of Australia during the Neogene, as they do now.

Thus the only evidence lacking in the Neogene, for the time being, is of the present arctic and antarctic conditions. All other belts, the northern and southern temperate-humid, the northern and southern arid, and the tropical humid, were much as they are now, with very similar dimensions and outlines. Another inescapable conclusion is, then, that the equator, the axis, and the poles were practically where they are now. Their deviation from the present position cannot be positively ascertained; if present at all it did not exceed 5 or 6°.

For lack of space, we cannot reproduce here paleoclimatic maps for the Paleogene, Cr_2, Cr_1, J_3, and J_{1+2}; we give, therefore, a most general description. Two of their features should be especially emphasized. All maps without exception show the North American and European-African-Asian dry zones at generally the same places where they were in the Neogene. All maps, except for J_{1+2}, show with certainty the South American arid zone, either in its northern part (Chile) or in its entirety. Differences between the paleoclimatic maps are only in the dimensions of the arid areas and their specific configurations. The dry areas on them either widen somewhat (J_3, Cr_2) or else contract; the latter is especially noticeable in the Liassic-Dogger. Tongue-like bulges originated at their edges, in places, often in fairly rapid succession. None of them, however, affected either the total number of arid areas throughout these geologic periods, or their basic location. In other words, the general plan of climatic zonation remained permanent, always the same in its major features. This enables us to speak with certainty of a general Mesozoic-Cenozoic, or Alpine, climatic zonation on the face of the earth, definitely persisting from the beginning of the Jurassic and into the present.

This similarity in the disposition of arid and humid zones implies that the orientation of the equatorial plane and the earth's axis has been about the same since the onset of the Jurassic. Deviations of the equatorial plane from its present position could not have been more than 5 or 6° of latitude; the deviation in longitude could have been greater, up to ± 15°. The actual deviaitions probably were much smaller. This limited displacement of the equatorial plane and the axis was, of course, the factor determining the great stability of the main paleoclimatic features which prevailed during this period of geologic history.

Another peculiar feature of the Alpine climatic plan deserves to be mentioned. Although the position of the equator and the poles were virtually the same as now, polar glacial provinces appear to be completely missing in this plan, during the entire Mesozoic and Cenozoic, with the exception of the Quaternary and the Recent. In any event, no definite evidence of northern and southern near-polar caps has yet been found. Considering the presence of woody plant remains and coal in high latitudes, during the Jurassic, Cretaceous, and Paleogene, it can be inferred that such caps were altogether non-existent at that time and were developed intensively only in the Quaternary, persisting into the present, in a reduced state.

3. CLIMATIC ZONATION IN THE LATE PALEOZOIC

A different climatic zonation plan, prevailing in late Paleozoic and partly in Triassic time, is best and most reliably revealed on the Late and Middle Carboniferous map which is as fundamental and indicative for that period as the Neogene climatic zonation map is for the Alpine stage.

Six climatic belts are definitely demonstrable for the Late and Middle Carboniferous (Figure 2).

The first stage is suggested by coal measures of Kazkhstan (Karaganda, Ekibastus, the Irtysh region), the Zaysan trough, Kuzbas, the Minusinsk trough, and partly the Tunguska basin. The plant association responsible for the organic bulk of coal is characterized by specific features. According to A.N. Krishtofovich [3], calamites, lepidodendron, and sigillaria were poorly developed, being represented by dwarf forms with evidence of stunted growth. Predominant were huge cordites forming a peculiar cordite tayga (virgin forest), and seed ferns, with cordite wood exibiting clean-cut annual growth rings. Such an aspect and composition of flora suggest, according to A.N. Krishtofovich, temperate climatic conditions with seasonal changes.

West of that area, the temperate zone probably extended across Greenland to northern Canada and into Alaska. However, there have been no findings, as yet, of the corresponding index rock.

To the south was a vast zone with definite evidence of aridity. Its extreme western part was located in the U.S., as witness the four areas of gypsiferous deposits in Utah (Paradox Basin, thickness about 460 m), Colorado (160 m), and Minnesota (16 m) [26]. To the east, across an immense gap without any evidence of climatic conditions, traces of aridity reappear on the Russian platform, in central Asia, and as far as China. As shown on a number of maps by A.B. Ronov for C_{2+3}(10), thick dolomitic sequences were laid down over immense areas of shallow sea then covering the Russian platform; their magnesium content was over 10% which corresponds to over 80% (and up to 100%) dolomitization. Characteristically, these dolomitic rocks were concentrated in the central zone of those seas rather than along their periphery; the rocks themselves are strongly marked by their qualitatively impoverished and commonly dwarfed fauna. At many points, boreholes penetrated anhydrite and gypsum among the dolomitic rocks. Judging from a recent work of I.V. Khvorova [21], these inclusions are mostly secondary, epigenetic, and due to the effect of highly saline ground water. However, alongside such metasomatic sulfates, there are stratified primary ones. Such were the formations encountered in the reconnaissance of Upper Carboniferous dolomites east of the Samara Bend (Krasnaya Glinka), as early as the pre-World War II years.

The presence of stratified and fairly thick gypsum in other parts of the platform is suggested by a very high average content of CO_3 in Visean and Middle and Upper Carboniferous sequences at various localities, noted by A. B. Ronov [10]. For example, the SO_3 content for C_2 was 33.67% in the Kel'tma borehole; 7.67% at Kotel'nich; and 5.64% at Soligalich. For C_3 it was 11.18% in the Vologda borehole; 17.66% at Gor'kiy; 8.61% at Kotel'nich; 13.05% at Krasnokamsk; and 8.77% at Soligalich. Such a high average SO_3 content cannot be explained by secondary sulfatization alone; we deal here, at least partly, with gypsum beds. This combination of a high dolomite content and local gypsum beds in deposits from central parts of an epicontinental sea suggests a shallow basin located in an arid zone; intensive evaporation raised its salinity somewhat and caused a chemical precipitation of dolomite from the bottom water; in insular areas, in small insular lagoons, salinity reached a stage where gypsum was deposited.

In Kazakhstan, southeast of the Russian platform, gypsum deposits occur in the Upper Carboniferous Kayraktin formation (gypsiferous shale intercalations) as well as in Middle Carboniferous redbeds (gypsiferous sandstone) of the Vladimir formation, in the basin of Ishim and Ters-Akkan Rivers [8]. In the Dzhezkazgan area and south of there, in Bet-Pak-Dal, the so-called gypsiferous marl formation known in many localities is supposed to be Upper Carboniferous to Permian [13]. Still farther south, across a wide gap, there lie the Tyan'-Shan' Middle Carboniferous anhydrite sequences (Lake Sonkul', etc.). There are no data, farther east, but probably the Upper Carboniferous gypsiferous red Soganpoo formation of western Shan'si underlies the coal-bearing Tolopay formation carrying a Permian flora [20]. On the whole, gypsiferous deposits make up a large zone of clearly defined arid conditions.

Inasmuch as the American and the Eurasian arid provinces are fairly distant from one another, a question arises as to whether they form a discrete arid zone or represent two individual arid provinces as in the Alpine stage. Any solution to this problem will be a hypothetical one, of course, on the premise that, as a result of the Caledonian orogeny, the North American, Greenland, and Russian platforms were put together to form an immense northern continent in juxtaposition with the southern Gondwanaland. Under such conditions, it is very probable that the American and Eurasian arid provinces, in Late Carboniferous time, formed a single dry zone,

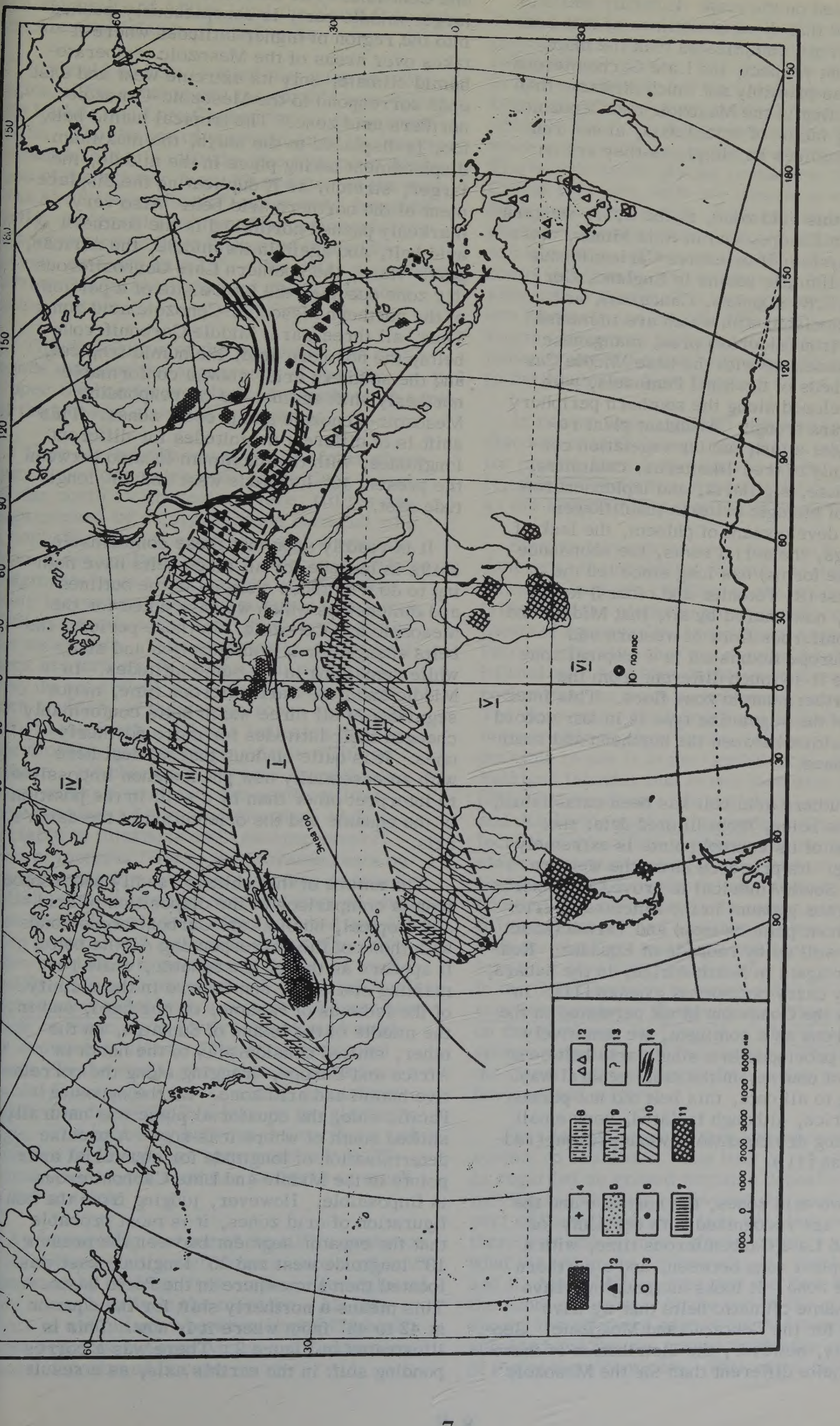


FIGURE 2. Climatic zonation for Middle and Late Carboniferous

I - humid tropical zone; II - northern arid zone; III - southern arid zone; IV - northern temperate zone; V - southern temperate zone; VI - southern near-polar zone; Symbols the same as in Figure 1.

as represented on the map. It hardly needs to be mentioned that the true outlines of that zone were much more complicated than the map shows; in that respect, the Late Carboniferous arid zone was probably not much different than those prevailing in the Mesozoic and Cenozoic. The limiting factor of actual data, alone, renders these outlines as simple as they are on the map.

South of this arid zone, in the U. S., western and southern Europe, and in Asia Minor, there is a large system of extensive Carboniferous paralic and limnitic basins in England, Germany, U. S. S. R. (Donbas, Caucasus), and Turkey, associated with which are immense deposits of iron (siderite) ores; manganese ores are associated with the base Middle Carboniferous beds of the Sinai Peninsula, with bauxite developed along the southern periphery of the Fergana trough. Abundant plant remains suggest a lush earlier vegetation consisting mainly of tree-like ferns, calamites, sphenophyllise, sigillaria, and lepidodendron. A number of biologic criteria (cauliflower effect, the development of phloem, the lack of growth rings, the aerial roots, the abundance of liana-like forms) has long since led the paleobotanist (R. Potonier and others) to the conclusion, now shared by all, that Middle and Late Carboniferous flora of western and southern Europe flourished in a tropical zone which made it so much different from the present northern humid zone flora. This interpretation of the vegetation type is in fair accord with its position between the northern and southern arid zones.

This southern arid belt has been established, for the time being, from limited data; the distribution of its control points is extremely interesting. Its presence along the western border (in South America) is proved by Upper Carboniferous gypsum in the Amotaka district (northernmost point on map) and Tarma (south point), as well as by redbeds of Equador. Redbeds occur again in North Africa, in the Sahara, where they carry occasional gypsum [11]. Inasmuch as the Gondwana block persisted in the Carboniferous as a continent, we tentatively unite both provinces in a single arid belt delineated, of course, in the most general way. According to all data, this belt did not persist east of Africa, although isolated, very small areas having dry conditions were present (redbeds of Iraq [11]).

Thus two arid zones, the northern and the southern, are recognized with certainty for Middle and Late Carboniferous time, with a humid tropical zone between, and a northern temperate zone. It looks as though we have here the same climatic belts that we have identified for the Cenozoic and Mesozoic. Geographically, however, the distribution of these zones is quite different than for the Mesozoic and Cenozoic. The northern arid belt, in its larger middle part, is conspicuously pushed into the region of higher latitudes where it takes over areas of the Mesozoic temperate-humid climate; only its extreme west and east ends correspond to the Mesozoic-Cenozoic northern arid zone. The tropical humid belt, too, is displaced to the north, the maximum displacement taking place in the middle, the larger, stretch, as if duplicating the displacement of the northern arid belt. Also very markedly pushed northward is the southern arid belt, and again in its middle, the African, part. Here, the southern Late Carboniferous dry zone occupies the future site of a portion of the northern Mesozoic-Cenozoic arid zone. Thus, all three warm Middle Carboniferous belts, the northern arid, the humid tropical, and the southern arid, show a conformable northerly shift against the corresponding Mesozoic-Cenozoic and present zones. This shift is of different magnitudes for different longitudes, with the maximum located between the present 10° longitude west and 20° longitude east.

It is readily seen that these conformable shifts in latitude for all three belts have nothing to do with those changes in the outlines and dimensions which we have noted for the Mesozoic and Cenozoic. In those periods, the belts changed their configuration and size, while remaining in the same latitudes. In Middle and Late Carboniferous time, major segments of all three warm belts conformably changed their latitudes for more northerly ones. It is quite obvious that we deal here with an essentially new phenomenon impossible to interpret other than by a shift in the position of the equator and the orientation of the earth's axis.

The nature of this shift is readily understood from a comparison of the disposition of arid and tropical, humid Late Carboniferous zones with those of the corresponding Alpine belts. It appears as though the equator, while remaining stationary somewhere in the vicinity of the Isthmus of Panama, on one hand, and in the middle of the Island of Sumatra, on the other, shifted considerably to the north in Africa and Europe, dragging along the correlative humid and arid zone. On the opposite Pacific side, the equatorial plane was naturally shifted south of where it is now. A precise determination of longitude for equatorial apex points in the Middle and Late Carboniferous is impossible. However, judging from the configuration of arid zones, it is most probable that the equator segment between the present 10° longitude west and 20° longitude east was located then somewhere in the Paris basin. This means a northerly shift for the equator at 42 to 48° from where it is now. This is illustrated in Figure 2. There was a corresponding shift in the earth's axis, as a result

of which the South Pole turned up near the southern extremity of Africa, and the North Pole near the Aleutian Islands of the Pacific.

It should be kept in mind that such an orientation of the equator and the earth's axis during the Middle and Late Carboniferous is approximate. The degree of approximation is, however, considerable. In latitude, the maximum deviation of the equator from its position on the map was hardly more than 5° either way; longitudinally, the position of maximum equatorial displacement could have fluctuated in a wider range, as much as ± 15°. The poles could have deviated from their mapped position by the same amount.

The disposition of the equatorial and polar zones explains the appearance of specific Upper Carboniferous glacial formations on some of the present southern continents.

They are best known in South Africa where they cover the entire area of the Cape trough, as far north as Rhodesia. Here, tillites are represented by an argillaceous material with a haphazard inclusion of assorted fragments, from a few millimeters to 2 m across. These fragments have all the traces of glaciation: their larger surfaces are polished to a luster, with numerous striations; smaller faces are not as smooth. Petrographically, these boulders are extremely diversified; as a rule, they do not reflect the bedrock composition, with boulders of indigenous rocks occurring only in the north. All this indicates the unquestionably glacial origin of this tillite sequence. Its character changes appreciably, from north to south. In the north, tillites have features of a ground moraine, highly variable in thickness and reaching several tens of meters. Here, the moraine rests on a very rough Pre-cambrian surface of sharp relief, with ridges and deep and narrow canyons. The bedrock surface is often polished and shows deep grooves and striations oriented usually from southwest to northeast, in places meridionally. In some places the floor relief displays roches moutonnées with a clearly different character on their north (or northeast) and south (or southwest) sides. There are giant cauldrons. In the south, the tillite beds take on a glacial lacustrine aspect. Here, glacial material was deposited in a lake by the glacier's edge. The boundary between the northern and southern facies passes approximately at 33° latitude south; the southern facies is as much as 300 m thick.

An interesting feature of the tillite sequence is its differentiation into several morainal units separated by boulder-free clays. Fluvioglacial beds occur locally in the moraine. All this points to a similarity between Upper Carboniferous deposits in South Africa and Quaternary glacial deposits of Europe.

The Carboniferous glaciations was not general; however, according to South African geologists, it did have no fewer than four independent centers. The first one was located in Nama province, not far away from the Atlantic coast or perhaps in the present Atlantic littoral zone. Ice moved from there to the south and southeast, as far as the Orange River. The second small glacial center was located in Griqua province, with ice spreading in all directions from there. A large Transvaal glacier existed in North Transvaal and Southern Rhodesia. It moved in wide belts, to the south, southwest, and southeast. It is possible that a branch of it was directed to Southern Rhodesia and into the Congo trough. The fourth center was located east of the present Indian coast of Africa, with the glacier shifting to the southwest from there.

In recent years, glacial deposits have been discovered in the Congo trough, as well, with ice moving here from south to north. Obviously, that ice sheet was fed from the same center as the southward moving ice of South Africa.

Similar formations were found in South America, the so-called Itarare series [24] Areally, they are confined to the southern extremity of the platform, partly to adjacent segments of a geosynclinal zone (South Argentina). Petrographically, they are a typical boulder clay (tillite) with boulders of the most diversified rock types, as much as one meter across. The floor under the Itararé series usually is inaccessible to observation. However, it was possible to see it in the Cordilleras, on the Falkland Islands, and in two localities in Brazil [28]. It turned out to be polished, striated, and displaying roches moutonnées. Occurring locally in this tillite sequence are banded clays or intercalations of sand with small boulders, which in places fully replace the boulder clay. Present in the upper part of the tillite sequence, and sometimes above it, in both the platform and the Cordilleras, are lentils of clay with remains of a marine fauna. In the Cordilleras it is represented by Spirifer supramosquensis, Chonetes, and Pleurotomaria; on the platform, by Lingula, Orbiculoidea, sponge spicules, and fish scales. Thickness of the Itararé series ranges from a few tens to a few hundred meters.

The glacial nature of this sequence is not subject to any doubt. The bulk of the tillite is regarded as ground moraine deposited by moving ice which then covered the southern part of South America. It is not clear whether there was one or more glacial centers and in what direction the ice moved. H. Gerth [24] and R. Maak [28] assume that the flow was to the south and west. At the end of the glacial epoch, the southern part of South America subsided and the sea transgressed the edges of the present continent. Part of the tillite,

then, represents glacial-marine deposits.

Both the South American and South African glacial sheets undoubtedly were of a continental origin; in that sense, they were similar to the Quaternary glaciation of Europe and North America. Ice sheets extended as far as 45 to 50° (contemporaneous) south latitude, i. e., on the whole as far from the South Pole as Quaternary ice was from the North Pole. In all these respects, Late Carboniferous glaciation of the southern hemisphere is quite similar to Quaternary glaciation in the north. The similarity is further emphasized by the fact that both glaciations were multiple, with ice advances alternating with interglacial stages.

Glaciation of Hindustan and southeastern Australia was of a completely different nature.

In India, glacial Talchir beds are represented by banded green clay and thin sandstone with abundant unweathered feldspar grains. The clay contains layers with fragments of the most diversified rock types (granite, crystalline schist, etc.) carrying definite traces of ice polish and striation. According to the Indian geologist, D. Wadia, these boulder beds are mostly glacial-lacustrine, with the boulders transported by melting icebergs. Locally, however, in the central part of the peninsula, boulder clays take on the features of ground moraine, with striated floor, polished, and shaped into roches moutonńes. The mother glacier was the present site of the Aravalli Range whence ice flowed out in all directions, into glacial lakes.

In southeastern Australia, glacial deposits are marked by their great thickness. They belong to the Kutting tillite formation, fluvioglacial conglomeratic sand accumulations, and lenticular glacial clays, on one hand; and even thicker (up to 1000 m) bodies of andesite lava and tuff, on the other. The latter also occur in glacial-lacustrine deposits.

The odd aspect of Indian and Australian glacial formations is their occurrence in the Late Carboniferous equatorial zone (Figure 2), i. e., in a humid tropical zone which they locally replace.

What is the interpretation of this occurrence? According to the well-known views of A. Wegener, it means that the position of India and Australia on the face of the earth was different in the Late Carboniferous. Together with South America, Africa, and Antarctica, they formed a single sialic block within which the contemporaneous south pole was located, off the present southern tip of Africa. In the Mesozoic, this sialic monolith was split up into individual blocks which then spread about to form the present continents of America, Africa, Antarctica, and Australia as well as the Hindustan peninsula in Asia.

This hypothesis, very popular in the twenties and early thirties of this century, lapsed then into near oblivion, only to be revived in recent years by many geologist, chiefly on the basis of paleomagnetic observations. Its advocate in the U.S.S.R. is, among others, P.N. Kropotkin who has recently published an interesting survey of paleomagnetism [4]. Despite the apparent plausibility of the Wegener speculations, I cannot agree with them because they contradict certain other paleoclimatic data on the Late Paleozoic of Australia. The fact is that, according to F. Lotze [27], gypsiferous deposits have been discovered in the Lower Carboniferous, at Kimberley, Australia. This means that in C_1 northern Australia, located very near the site of a later glaciation, was still in lower latitudes, somewhere between 20 and 30° of the contemporaneous latitude, i. e., near the equator. Red gypsiferous beds also were discovered in Upper Permian deposits of western Australia according to F. Lotze [27]. Consequently, in Late Permian time, Australia lay in lower latitudes, near the equator. With this in mind, if we insist on the Wegener hypothesis, we imply that in post-Early Carboniferous time, Australia paid a visit into higher latitudes where it was covered with ice, in C_{2+3} and the beginning of P_1. After that it came back home, so to speak, to lower latitudes. The contrived and artificial aspect of such an interpretation is obvious and requires no further comment.

Thus, these data of F. Lotze on the presence of Lower Carboniferous and Middle Permian gypsiferous deposits C_1 and P_2 in Australia invalidate the concept of A. Wegener (and his followers) in the very area for which the concept was derived and where it has been so widely and effectively used. With this out of the way, a new explanation of late Paleozoic glaciation in Australia and Hindustan must be sought.

Up to now, the development there of late Paleozoic glaciers has been regarded as a phenomenon of the same order of magnitude as those in South American and South Africa: the Indo-Australian ice was interpreted as the result of a continental glaciation. Now that it is clear that they are associated with an Late Carboniferous (and P_1) — Early Permian tropical zone, such an interpretation is obviously invalid. The only possibility is to regard them as mountain-type glaciations, the result of very high Late Carboniferous uplifts in the equatorial zone.

Preserved in India, besides the Aravalli Range moraines, are deposits of mountain lakes into which glaciers descended and dumped their load. In Australia, mountain ranges which stood up in a geosynclinal zone as the result of folding then in progress were not only covered with glaciers which left their moraines behind them but often were centers of lava flows and

of the eruption of huge bodies of hot ash. The eruption heat rapidly melted large areas of ice, with the resulting mud flows, resembling sills, flowing to the sea and carrying along unsorted material to form glacial marine deposits. A frequent recurrence of this process was responsible for the formation of abnormally thick glacial deposits.

If this interpretation is correct, and it appears to be the only possible one, it reveals a new feature in Middle and Late Permian climatology, a feature we also observe at the present geologic time: a vertical zonation of climate.

The assumption of a vertical zonation in the Middle and Late Carboniferous affords an interpretation for another feature of late Paleozoic history, a peculiar distribution of terrestrial floras. Two similar floras, more like a bipolar flora, were in existence: the Gondwana and the Tunguska, in the southern and northern temperate zones, respectively. Present between them in India and Australia, i.e., in the tropical zone, was more of the Gondwana flora, the temperate zone type, as witness plant remains. Its only explanation is that its site was lofty highlands whose highest elevations were marked by glaciers. The very origin of late Paleozoic floras was probably due to the fact that some ancestral tropical forms, migrating simultaneously into the northern and southern temperate zones, produced a bipolar Gondwana-Tunguska flora; in migrating to higher elevation of a tropical plateau, with its temperate climate, the same ancestral forms naturally produced there an ecologically similar Gondwana flora of India and Australia.

Thus the data extant on Middle and Late Carboniferous climates shape up into a consistent picture - peculiar, to be sure, but devoid of inner contradictions. Its background is very different from the present position of the equator (it is inclined to it at 45°) and correspondingly of the earth's axis. This resulted in a conspicuous northerly shift of the three warm climatic zones in Europe and Africa; and their corresponding southerly shift in the opposite hemisphere. Standing out on this general background is a vertical climatic zonation in the equatorial belt, culminating in glaciation of highlands.

A logical question arises — when did this shift of warm zones take place? And how long did the equator and the poles remain in that position?

A study of the paleoclimatic maps of the Lower Carboniferous on the one hand, and of the Permian on the other hand, shows that the zonality of these periods in its essence and principles corresponds fully, in plan or type, to what we have seen in C_{2+3}. The only difference consisted in the fact that in C_1 the arid regions, especially the northern ones, were considerably reduced, whereas in the Permian they had a far greater area than that observed in the Middle and Late Carboniferous epochs. In the Devonian, however, there is the beginning of a different, or third, paleoclimatic zonality, and in the Triassic there is a clearly marked transition from a Late Paleozoic zonality to a Mesozoic-Cenozoic zonality. Thus the period during which the second plan of climatic zonality existed corresponds almost completely to the Hercynian tectonic stage, so that the plan itself can be called Hercynian.

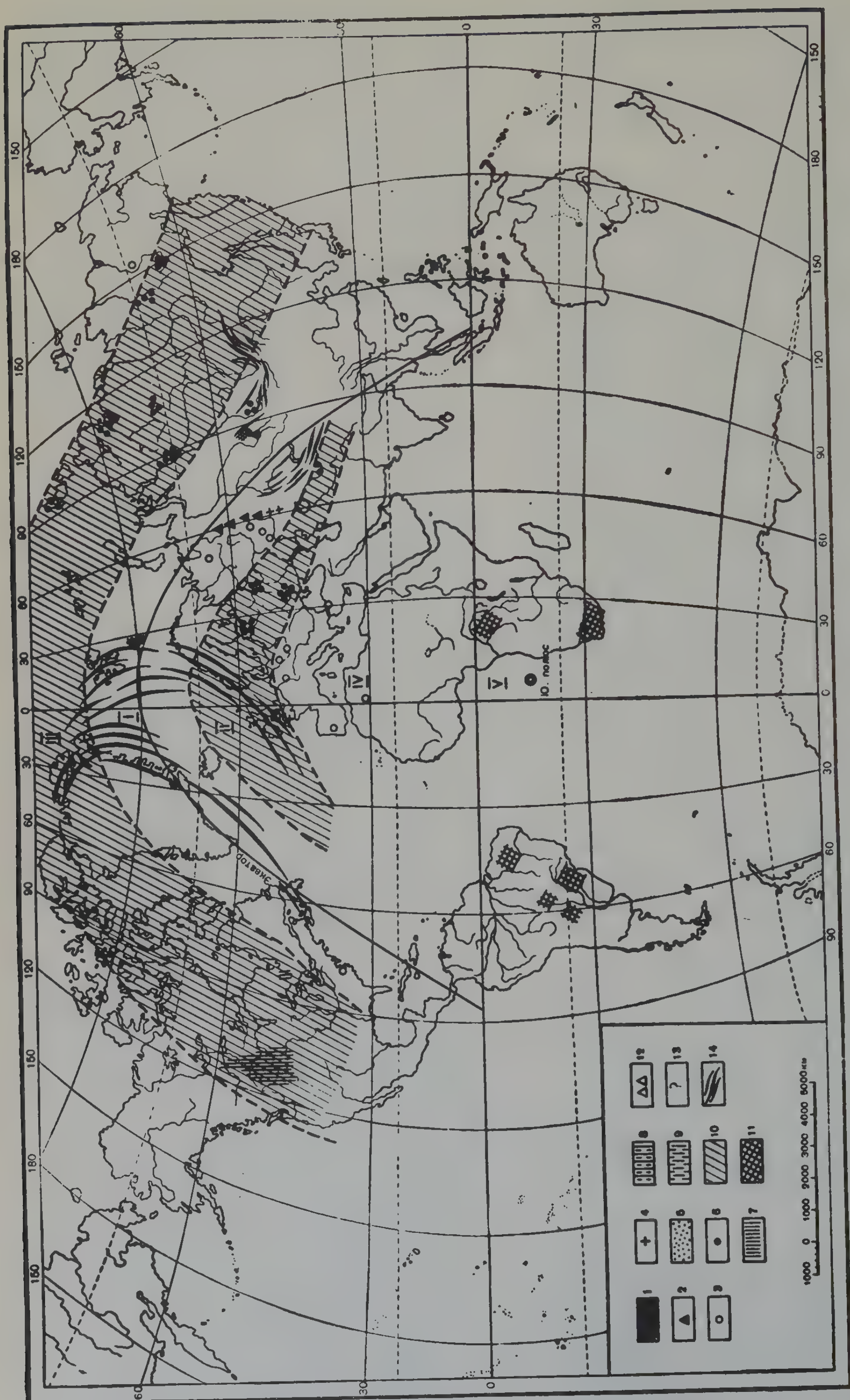
4. CLIMATIC ZONATION INDICATED IN LOWER PALEOZOIC SEDIMENTATION (DEVONIAN, SILURIAN AND ORDOVICIAN)

The older the periods of the earth's history under study, the scarcer the data for a reconstruction of their climatic zonation. This is ever so much more discouraging because the farther back we go, the more peculiar and unlike the recent is the climatic zonation of the past.

As a matter of fact, we can construct but a single reliable paleoclimatic map for the Devonian, Silurian and Ordovician, namely for the Middle Devonian, by using the data from both of its stages, the Eiffel and Givetian. This map is presented in Figure 3.

Four zones are outlines. The northernmost is the northern arid zone. In the west, it may be recognized by deposits of gypsum and salt, in the U.S. and Canada. A thick sequence of Middle Devonian anhydrite and salt was laid down in Manitoba, Alberta, and Saskatchewan. It disappears to the south, replaced in Montana by Upper Devonian gypsum, which corroborates the persistance of arid conditions in that part of the American continent. Southeast of there, in Iowa and Michigan, gypsum and salt are also Upper Devonian (in Michigan), but it is very probable that arid conditions prevailed there as early as the Middle Devonian and only an unfavorable environment prevented the formation of halogen deposits.

Across an immense "empty" gap, a long series of gypsiferous and locally salty deposits recur in northeastern Asia, stratigraphically well-dated [1]. Thus the Upper Devonian of islands Pioneer, Komsomolets, and the October Revolution is represented by cross-bedded red sandstone, marl, and limestone intercalations with armored fish remains, as well as by limestone-dolomite and gypsiferous sequences with Favosites goldfussii, etc. The Taimyr Givetian stage, 300 to 400 m thick, is made up of limestone, dolomite, and gypsum and carries a typical stringocephalian fauna. Assigned to the Givetian stage on Yurung-Tumus Peninsula (Nordvik area) is the upper part of the gypsum, anhydrite, dolomite, shale, and limestone sequence, 250 to 350 m thick, directly underlying the fossiliferous Frasnian deposits. On the Siberian platform, in basins of Khantayka, Kureyka, Nizhnyaya Tunguska rivers, in the Noril'sk area, and in the upper course of the Olenek, the Middle Devonian consists of motley



Фиг. 3.

FIGURE 3. Climatic zonation for Middle Devonian

I - humid tropical zone; II - southern arid zone; III - northern arid zone; IV - southern temperate zone; V - southern near-polar zone. Symbols the same as in Figure 1.

shales, siltstones, and sandstones with plant remains and intercalations of gypsum and dolomite. In the extreme northeast, in the Momsk, Tas-Khayakhtakh, and Setta-Daban anticlinoria, gypsum and anhydrite occur with Givetian shale.

All these findings outline an immense northwest-trending zone of a definitely arid climate. It extends obliquely from 81 or 82° to 60° latitude north. It remains uncertain, whether or not it joined the arid area of North America. Tentatively, and to represent the unity of the northern arid zone, a transition is indicated to the American zone. We add that somewhat to the west of this northern arid zone we observe a peculiar Eiffel salt sequence in the south of the Tuva trough and in adjacent parts of Mongolia, recently described by N. S. Zaytsev [2] and A. I. Levenko [5]. According to G. I. Teodorovich [19], Middle Devonian gypsum beds are also developed in the Minusinsk trough, in both the Eiffel and Givetian stages. Local arid areas most probably persisted here in depressions between the newly risen Caledonian Ranges. In the northeastern part of the U. S. S. R., there is evidence of another, humid environment, as demonstrated by the iron ore deposits recently discovered by Pobedinskiy (Z. P. Potapova, 1959).

South of the arid zone there was a belt characterized by humid conditions. Definite traces of it occur only in the Urals and in the eastern part of the Russian platform. On the eastern slope of North Urals there is a long belt of Eiffel bauxite deposits, over 250 km long. The same belt contains bauxite at the base of the Givetian stage; areally, they are even more extensive than the Eiffel, inasmuch as they persist as far as the middle Urals. In Timan, coal and iron ore are associated with the very base of D_3; obviously, similar climatic conditions persisted here up to the end of D_2. According to L. M. Miropol'skiy and his collaborators [7], beds of oölitic hydrogöthite-chamoisite in the second Baku Area, Bashkiriya and southeastern Tataria, belong to the Givetian stage (Ardatov unit). According to M. A. Rateyev [9], argillaceous deposits of this unit always carry an appreciable addition of kaolinite. All this constitutes definite proof of a humid specifically a warm humid, climate prevailing southeast of the arid zone.

For the time being, it is impossible to trace this zone east of the Urals, for lack of index facies. Nevertheless, it should be noted that bauxite occurs in Middle Devonian beds of Salair and peculiar coals (Barzas sapromixites) occur in the northeastern corner of the Kuznetsk trough. It is quite probable that humid conditions prevailed here in the Middle Devonian. West of the Urals, the humid belt is traceable only from indirect data, such as coal deposits at the base of D_3 on Medvezhiy (Bear) Island and the Oriskany D_1 ores in the Appalachian province. Without providing a decisive argument, these two localities render probable a western extension of the humid zone as far as eastern North America.

Another belt of arid climate lies to the south. The westernmost points suggesting its existence are the Old Red deposits in England. Farther on to the east there lies a vast area of development of dolomitic rocks with gypsum lenses, embracing, according to A. B. Ronov [10], the Baltic region, the main Devonian field, and most of the Moscow synclise. Thick beds of salt appear at the very center of that area, between Moscow and Tula (cities of Zubtsov, Borovsk, Serpukhov, and Tula). In the Ukrainian trough and Donbas, gypsum and salt of the Romny salt domes should be assigned to the Middle Devonian, inasmuch as limestones with a Frasnian fauna have been brought to the surface with salt breccia. Evidence of anhydrite deposition is present in places west of Donbas as well, in the Bessarabian Dniester region. Definite traces of gypsum and salt disappear farther southeast; however, south of the Kazakh folded province this series may include deposits of anhydrite and gypsum in the Sarysuy domes and betpakdalin structures. As estimated by students who worked there (B. A. Petrushevskiy, N. S. Zaytsev, etc.), the age range of pre-Visean gypsum possibly embraces an interval from the Early Devonian to the end of the Tournaisian. Definitely Givetián are gypsum beds of the Talas Alatau [6].

On the whole, the south arid zone is horseshoe-shaped, similar to the trend of the corresponding northern arid zone.

South of there, there is evidence of a humid climate a series of iron and maganese ore deposits extends from Cornwall (manganese ores) across Belgium (oölitic red ferruginous rocks of the Ardennes of the Lower, Middle, and Upper Devonian), to the Rhine province, Hartz, and the Sudetengebirge. South of there, Middle Devonian oölitic iron ores are known from Turkey and Sahara (Tinduf area). Unfortunately, there are no definite traces of a humid zone farther east; its extension on the map is shown as tentative.

It goes without saying that the boundaries of these three climatic zones are approximate, subject to slight change on the basis of new data. However, the basic feature of Middle Devonian climatic zones in northwestern Eurasia, their disposition in bands strongly deflected to the north, as in the late Paleozoic, has been established with some certainty.

On the other hand, there is a noticeable and essential difference in the position of late Paleozoic and Middle Devonian climatic zones. It is expressed in the fact that all three warm zones of northwestern Eurasia lay much farther north, during the Middle Devonian than in the late Paleozoic. The northernmost point of the Middle Devonian equator in that part of the earth fell at about 75° north latitude, with the South Pole at about 15° south latitude. In other words, the Middle Devonian equatorial plane was shifted north by at least 30° compared with its late Paleozoic position in Europe; on the opposite Pacific hemisphere, the other half of the equatorial plane was correspondingly displaced to the south.

In my earlier works [17, 18] on climatic

zonation of Eurasia in the late Paleozoic and especially in the Devonian, written without the new data on the Siberian platform and New Siberian Islands, the arid zone passing through the Russian platform was regarded as the northern zone, while a humid zone extending across the Urals and into the west Siberian plain was regarded as the northern temperate zone. Now that the data on Siberia and northeastern Asia are at hand, the error of that interpretation is quite obvious. The zone passing across the Urals and west Siberian plain should be regarded, from all data extant, as the humid tropical zone.

This interpretation provides a better explanation for a number of facts which fit into the old concept with some difficulty. Among them is the extensive development of bauxite in this zone in large amounts, which, from what we know of the formation conditions for these rocks, corresponds better to a humid tropical zone than to any other. It is not an accident that the earliest coal accumulations appear in this very tropical humid zone with its high humidity and temperatures, most favorable for an intensive growth of psilophyes, the first brushwood forms of land plants. Nor is it an accident that first remains of the skulls of Devonian stegocephalians were found in Greenland, i. e., also within the Devonian tropical zone: the passage of animals from sea to land and the change from gill to lung breathing should have been the easiest in the tropics with their air very rich in water vapor.

The proof of this interpretation is found, however, not only in the northern hemisphere but in the southern, as well.

With the position of the Equator so assumed, the South Pole would be located somewhere in the vicinity of 15° south latitude; consequently, Central and South Africa were within the near-polar province. Correspondingly, the North Pole was located in the Pacific. This implies the presence of ancient glacial deposits within Gondwanaland. Such evidence indeed is there.

First, there is the so-called Table Mountain formation developed in the southern part of Africa, in the Cape mountain system; according to A. Du Toit, it is Upper Devonian (or uppermost Silurian?). This is a sandstone sequence of immense thickness, with thin shale units in its upper and lower parts. We are interested only in the upper unit, about 100 m thick. A. Du Toit states [22], "Its lower part is formed by non-stratified green-blue to reddish shale with occasional pebbles and boulders. The latter consist of quartz, quartzite, sandstone, red jaspers, amygdaloidal diabase, and granite. Their distribution in a fine-grained matrix is haphazard and independent of size." Boulders and pebbles are striated, despite their hardness. This boulder-carrying sequence is reminiscent in many respects of the Dwika Upper Carboniferous tillite whose glacial origin is unquestionable. Transition from the morainal unit to the underlying sandstone and the overlying shale sequence is gradual. "There is no striated floor at the base of these glacial formations" ([22], p. 192). However, in one locality within the area of their distribution, the underlying rocks form sharp local folds, 50 to 60 m deep, with truncated apices, which are undoubtedly glacial dislocations.

All these data present a fairly convincing evidence of some Devonian glaciation at the south tip of Africa. "Glaciers," Du Toit goes on, "not very large ones perhaps, covered the surrounding mountains for some time. Their melting produced a flow of glacial outwash deposited as a shale bed. After that, normal conditions were restored" ([22], p. 195).

We are especially interested in the fact that in the depostion of the Table Mountain formation, including the glacial unit, material was brought from northwest or west, with relation to the present situation. This means that "the glacial area, as far as it can be ascertained, was located somewhere to the west or northwest" ([22], p. 192). This is in full agreement with our assumed position of the Middle Devonian South Pole, arrived at from a different line of evidence.

The two glacial units long known from the upper Kundelungu system in the Congo basin, considerably to the north are even more interesting. The lower of the two is Precambrian, and the upper, the thicker one, "may by correlative with the Table Mountain tillites of the Cape system" ([12], p. 124), i. e., with the glacial series described above. Here, the transition from glacial to fluvioglacial deposits proceeds from southwest to northeast.

Very recently, R. Maack [28] published some reliable evidence of glaciation in southern Brazil. On the western flank of the Parana trough, 22 km west of Castro São Joaquim district), the base of the Devonian carries a shale and conglomerate member of definitely glacial origin. It rests unconformably on an uneven porphyritic floor and is 7 to 15.8 m thick. R. Maack unites, "...at the base is a unstratified and unsorted unit, 6 m thick, reminiscent of tillite. It is followed by a 5 m-thick, slightly stratified layer carrying boulders... The ground mass is vivid brown-red, due to iron oxides... The culminating layer, 1.5 to 3 m thick, is gray-blue and shows no stratification. However, a closer examination of this layer reveals that it, too, is crypto-stratified, with assorted boulders floating in its poorly sorted groundmass. The boulders exhibit a definite glacial striation." R. Maack interprets these deposits as a ground moraine laid down in a lake; this is corroborated by the fact that farther north the morainal deposits take on a sub-aqueous

spect, i. e., change to drift conglomerate and acustrine sediments. These glacial deposits re exact correlatives of the Table Mountain lacial deposits of South Africa, being either erminal Gotlandian or Lower Devonian. Simi- ar formations have been observed by R. Maack omewhat to the west, in the Cordillera front.

It is readily seen that all these occurrences f Lower Devonian glacial deposits are in ex- ellent accord with the position of the South ole, assumed on the basis of quite different ndependent data.

All this suggests that our general plan of Iiddle Devonian climatic zonation is correct nd that its substantial differences from the ate Paleozoic climatic plan were really as tated.

Again these questions arise: when did the hange from one plan to another take place? nd for what older epochs can a similar cli- atic zonation be established?

Its upper boundary is the beginning of the arboniferous, because a Hercinian type of limatic zonation was present as early as C_1. s lower boundary is uncertain. The only ertain thing is that data on the climate of the otlandian and Ordovician fit without any strain to the above-described Devonian plan. The w certain suggestions of Cambrian arid zones so fit into it. It is not impossible, then, that is plan prevailed during the entire Caledonian age. For this reason, it can be termed, some- hat conditionally, the Caledonian plan (or type) climatic zonation.

5. GENERAL PLAN OF EVOLUTION OF CLIMATIC ZONATION IN THE POST-PROTEROZOIC

Summing up all our data, the following facts n be considered definite on the climate of st geologic periods.

1. During post-Proterozoic time, a succes- on of three climatic zonations, clearly differ- g from one another in the disposition of warm lts with reference to the present equator igure 4), developed.

In early Paleozoic time the equatorial plane is so oriented that it cut the 0 to 10° east eridians at about 75° to the present equatorial ane. The North Pole was located almost at e center of the Pacific, with the South Pole off e coast of Africa. The northern arid zone tended from the U.S. almost across the pre- nt pole, into the area of Franz Joseph Islands, vernaya Zemlya, and the Siberian platform. e southern arid zone embraced the northern rt of the Atlantic, England, the Baltic shield, e central part of the Russian platform, and Central Asia. Between them, in the regions of south Greenland, Novaya Zemlya, the Urals, and west Siberia, there lay the humid tropical zone.

In late Paleozoic time, the equatorial plane cut the 0-10° east meridians at 45° to the present equatorial plane. The North Pole was located near the middle of the Aleutian Islands, the South Pole near the south tip of Africa. The northern arid zone extended in a wide belt from the western U.S. across Labrador, the southern tip of Greenland, Iceland, and as far as the Baltic shield; thence obliquely to the southeast corner of the Russian platform and into Central Asia. The southern arid zone extended from Brazil to North Africa and thence to western Australia. The tropical humid zone took in the eastern U.S., western and southern Europe and continued into southern Asia and northern Australia.

The Mesozoic-Cenozoic plan of climatic zones, from the Jurassic on, correspond to the present one, without any substantial differences.

2. The presence of these three consecutive plans of climatic zonation suggests the three stages of evolution of post-Proterozoic climate. The duration of each stage was about 150 to 170 million years. Chronologically, the climatic stages correspond on the whole to tectonic stages of development of the earth except for a characteristic time shift. Thus the Caledonian climatic stage ends in the Devonian; the Hercinian one opens in C_1 and closes in the Triassic; and the Alpine begins in the Jurassic and is still continuing (Figure 4). Consequently, each climatic stage lags somewhat behind the corresponding tectonic stage, with respect to both its beginning and end.

3. Undoubtedly, the inclination of the equatorial axis and the corresponding position of the earth's axis did not remain strictly fixed during each stage. Unfortunately, the lithologic and paleontologic data extant are inadequate to trace any changes with certainty. All that can be said is that their amplitudes were very small, within the limit of error for paleoclimatic maps. As repeatedly pointed out above, this error is not over ±5 to 6° for the latitudinal shift of the equator and ±15° for the longitudinal shift of its two apex points. Within that range, the inclination of the equatorial plane and the corresponding position of the axis could have changed without being reflected on maps. It follows that the rate of such shifts could have been but very slow.

The situation was different in the transitional stages when one climatic zonation plan (type) changed to another, i. e., in the Late Devonian and Triassic. Here, the inclination of the equatorial plane, in each 20 to 25 million years, was about 40 to 45° for the Triassic and 30°

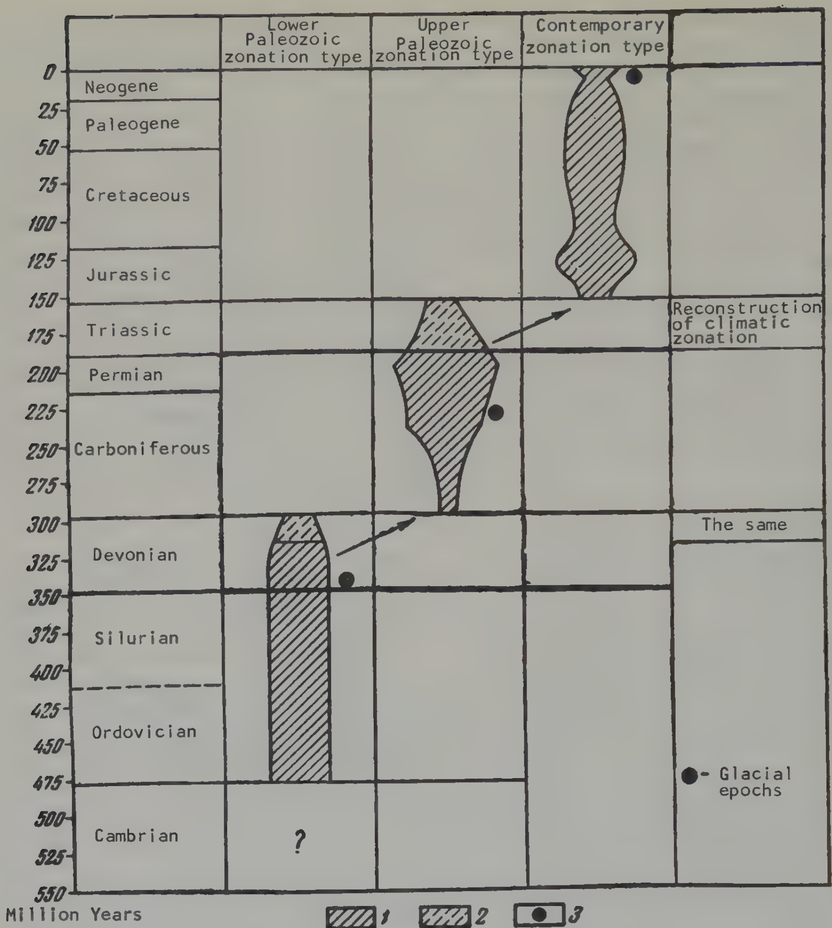


FIGURE 4. Evolution of climatic zonation in the post-Proterozoic history of the Earth.

1 - epochs of slow shifting of the poles; 2 - epochs of accelerated shifting of poles; 3 - glacial epochs.

during the Late Devonian, the average speed of displacement was about 18 to 19 cm per year. It is characteristic that this accelerated shift in the position of the equator and the axis is manifest at the end of each tectonic stage, when the tectonic events associated with it were completed or nearly so. On the other hand, during a tectonic stage itself, despite its recurrent orogenic movements, the rate of displacement of the equator and the axis was incomparably slower.

4. During entire post-Proterozoic history, the shift of the equator and the poles has been in the same direction, in such a way as to have the ancient equatorial plane, steeply (75°) inclined to the present one, approach and coincide, with it, in a series of consecutive movements. In this process, the earth's axis of rotation probably did not shift in the same plane; however, any deviations from it, judging from the maps, were not large, falling within a sector between 10° west and 20° east.

5. The outlines and dimensions of climatic zones changed appreciably both in epochs of slower displacements of the equator and the axis and especially in epochs of the change from one climatic zonation to another.

Especially characteristic climatic conditions were associated with Early Carboniferous and Liassic-Dogger epochs, i.e., the initial epochs of Hercinian and Alpine climatic planes. In both, there was a sharply defined humidization of climate over the earth's surface, i.e., an abrupt widening of humid zones at the expense of the arid ones. On the other hand, during the Late Permian, the Late Jurassic, and Paleogene, a widening of arid zones took place at the expense of the humid.

6. Along with fluctuation in the outlines and dimensions of climatic zones in various periods

here is some evidence of simple temperature hanges on the earth's surface; however, they re proved only for the last stage of the climatic volution. If the average surface temperature n the Early and Middle Jurassic be accepted s the datum, the Early Cretaceous appears to ave witnessed an appreciable rise in temperaure; during the Late Cretaceous and especially he Paleocene a lowering occurred, but to a evel higher than in the Jurassic. In the Eocene here was a new jump up to the Early Cretaceous evel, after which there was an uninterrupted owering of the temperature, continuing into he Quaternary when it reached the lowest of he Alpine climatic stage. Although such temerature fluctuations are as yet unknown for lder stages of climatic evolution, it is hardly o be doubted that their evidence will be unovered, in time.

7. The three known post-Proterozoic glacial pochs occurred during the slowed-down movements of the equator and the axis. Consequenty, they are not related to such movements.

5. SIGNIFICANCE OF CLIMATIC ZONATION IN SOME GEOLOGIC PROBLEMS

In conclusion, a few words on the significance f climatic zonation in some branches of geoogic science:

One of the most important current problems f geology is a study of regularities in the disribution of industrial sedimentary minerals. is readily seen that the maps described bove, of paleoclimatic zonation have a direct elation to this problem.

Indeed, all rocks, indexes of climate, are the same time most important, industrially. y outlining for each interval of geologic time he trend of its humid zones, we outline thereby rovinces which were favorable for the formaon of chemically weathered crusts, kaolin, acer deposits of gold, platinum, titanium, n, diamonds, and other heavy elements, and auxite, iron and manganese ores, and coal. utlines at the same time are provinces where eir formation was precluded. By the same ken, in outlining belts of arid climate, we esignate thereby zones potentially favorable r origin and mass accumulation of dolomite, upriferous sandstone, sedimentary ores of ad and zinc, gypsum, halite, potassium salts, uorite, celestite, borates, and bromine; outned simultaneously are zones unfavorable for e formation of any of these deposits. This eans that the climatic zonation of each geo gic epoch is at the same time a broad outline the areal distribution of a great number of ost important sedimentary minerals of indusial significance. It is, so to speak, the first pproximation in the knowledge of regularities their distribution.

A study of our paleoclimatic maps brings out other characteristic features, e.g., a very uneven distribution of any industrial mineral over the area of a climatically favorable belt.

Accumulations of any component within its favorable zone are concentrated in some places; on the other hand, there are large areas devoid of such deposits. Such condensed accumulations, with reference to coal, were named nodes, by P.I. Stepanov; I have designated as ore provinces similar condensed accumulations with reference to bauxite, and iron and manganese ores.

As I have pointed out on several occasions, there are two causes for the origin of ore nodes. One of them is the nature of tectonic conditions prevailing in different parts of a belt climatically favorable for mineralization. Ore nodes were formed where a favorable climate was combined with appropriate landscape and tectonic conditions; where the latter militated against mineralization, their effect counteracted, so to speak, the favorable effect of climate, and the disagreement between the two resulted in the lack of mineralization.

Another factor promoting the formation of ore nodes within climatically favorable provinces was the petrographic composition of water-collecting areas. The fact is that a number of elements (Pt, Au, Ti, Sn, diamonds, radioactive elements, and many other minor elements) occur in the crust in such small quantities that a preliminary concentration of them in the source igneous rocks is a prerequisite for their sedimentary accumulation. Ore nodes were formed where, besides a favorable climate and suitable landscape and tectonic conditions, there was a more or less sizable concentration of these elements in source rocks.

It is clear, then, that belts of sedimentary accumulations of any component are climatic zones which allow their formation, while nodes are provinces within these zones where the favorable climatic conditions work together with the landscape and tectonics, as well as with a suitable petrographic composition of the watershed. Thus, paleoclimatic maps constructed according to the principles set forth in the beginning of this paper are at the same time maps representing some basic regularities in the distribution of principal industrially important minerals. An analysis of those maps inthis light reveals the fundamental mechanism which controls this distribution. This sufficiently underscores their value in the theory of sedimentary industrially important minerals.

Moreover, climatic zonation as set forth in this paper pertains to another and no less important geologic problem, that of petrogenesis. Up to now, in their study of the structure of the

crust, and the tectonic movements responsible for it, geologists have tacitly based their ideas on the concept of the earth as a body whose axis of rotation (and consequently the equator) remained constant in the course of geologic history.

Our maps (and the data on paleomagnetism) prove that this premise is erroneous and that tectonic deformations of the lithosphere went on against a background of continual, slower to faster, shifts of both the earth's axis and the equatorial plane. At the present time, these shifts are no longer to be thought of as an invention, a bold guess, as was the case up to recently; nor is it a speculative concept to be ignored in a purely empirical study of deformations of the crust. These shifts are now a fact. Like any definitely established fact, of a major import at that, it can no longer be ignored in the study of tectogenesis. It should attract the concerted attention of students.

It is readily seen that shifts in the earth's axis of rotation and equatorial plane affect deformations of the lithosphere and induce some of their fairly large features. A study of crustal structure from this point of view becomes a current problem of tectogenesis.

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SOME FEATURES OF IGNEOUS ACTIVITY IN EGYPT[1]

(Resumé of observations by a delegation of Soviet scientists during their visit to U. A. R.)

by

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In February, 1959, six hours after our departure from Vnukovo airport and after a flight over the Carpathians, mountainous Albania, and the blue Mediterranean, our plane landed at Cairo airport. The purpose of this visit by Soviet scientists, at the invitation of the U. A. R., was the development of scientific ties between the two countries.

Our acquaintance with scientific institutions and schools of higher education in Egypt as well as with the land itself, its geology, and the monuments of its ancient culture produced a store of vivid impressions difficult to set forth in a brief article.

OUR ACQUAINTANCE WITH SCIENTIFIC INSTITUTIONS AND SCIENTISTS OF EGYPT

Scientific geologic study in the U. A. R. is carried on by geology departments of the four universities of the country: Alexandrian, Cairo, Ain-Chams at Cairo, and Asyute. The Mining Department of the Engineering College, Cairo University, and the Geology Department of the Institute for Desert Study also deal with geology and mining.

Associated with the Ministry of Industry is the Mineralogy Department, the Geological Survey, and the Bureau of Mines.

Egypt, a country which has recently gained its national independence, is taking strong measures for the development of its education and industry; for that reason, much attention is given to geologic study.

The comparatively small Geological Survey of the country carries on geologic surveying and exploration for ferrous and non-ferrous metals. Sands of the Mediterranean coast are studied for monazite. Aerial photography is used extensively in geologic study, which is quite natural under the local conditions. Geophysical methods are also used. Professors and instructors of the universities participate in these geologic explorations. Laboratory facilities are inadequate, from a modern point of view, in most universities.

The Egyptian Geological Survey operates with 70 to 80 geologists, holders of Ph. D., M. S., and B. S., degrees. It consists of the following sections: 1) regional geology, 2) exploration, 3) laboratory, 3) mining geology, and 5) museum.

Metallometric studies are carried on during surveying and mapping work at a scale of 1:100, 000 (for promising areas). The regional geology section has a task set up for it, i. e., to produce in 10 to 15 years a preliminary geologic map of Egypt on a scale of 1:500, 000. Geophysical studies (magnetometer, electric logging, etc.) are carried on in the vicinity of known industrial mineral deposits. Drilling of stratigraphic control holes is planned along with exploratory drilling.

The laboratory section operates laboratories of chemical analysis, benefication, metallurgic study, and optical mineralogy. Laboratories of spectrographic and X-ray analysis are planned.

The Scientific Research Center at Cairo is busy setting up various laboratories including those for geologic purposes.

The vast majority of scientific workers in geologic organizations are Egyptians with many young and talented geologists among them. Many young people attend the universities.

During my visits to geologic institutions and in our joint field trips to Eastern Desert, I was always conscious of the attention and good will displayed by Arab scientists. I take this

[1]Nekotoryye cherty magmatizma Yegipta.

opportunity to express our gratitude to Professor Tourky, Director of the National Research Center at Cairo (Foregin Member of the U. S. S. R. Academy of Sciences); Professor Higazy, Director of the Egyptian Geological Survey; and Professor J. A. M. Farag, Chairman of the Geology Department, University of Cairo.

The interesting field trips in the vicinity of Cairo were carried out with the pleasant companionship of Professor E. M. Shazly and geologist M. F. Ramly who kindly organized them and personally participated.

Geologists of Cairo and Asyute were very interested in achievements of Soviet geologists in the field of science and in solving practical problems.

I read two papers at the National Scientific Research Center: 1) Principal Scientific Problems of Geologic Research in the U. S. S. R. and Features of Its Organization, and 2) Training a Corps of Geologists at the U. S. S. R. Academy of Sciences.

For the students and teaching staff of the Geology Department, University of Cairo, I read a paper on "Granite Lamprophyres."

In their turn, Egyptian geologists gave us some new geologic publications and introduced us to their laboratories, museums, and some natural objects.

Out trip from Cairo to Aswan, by rail, with brief stops at Asyute and Luxor, and geologic field trips to the Eastern Desert between Ifdu station and the Red Sea, has given us a brief but unforgettable impression of the land, the people, and the monuments of the ancient history of Egypt.

EXTRUSIVE ROCKS OF EGYPT

The geology of Egypt is dealt with in the basic compendium by W. Hume. H. M. E. Schürmann has published a number of papers on the petrology of Egypt in Neues Jahrbuch. In the past decade, a number of works on geology and petrology of Egypt have been published by the Arabian geologists R. Higazy, E. M. Shazly, and others.

Crystalline rocks here are mostly concealed under Mesozoic and Cenozoic sediments and recent desert formations.

Extrusive rocks are widely distributed in the upper part of the Egyptian course of the Nile. The first outcrops of crystalline rocks appear in the Aswan area. The fall of the Nile here was used in the building of the first Aswan dam (Figure 1a).

According to E. M. Shazly [12], pre-Carboniferous and chiefly Pre-cambrian rocks

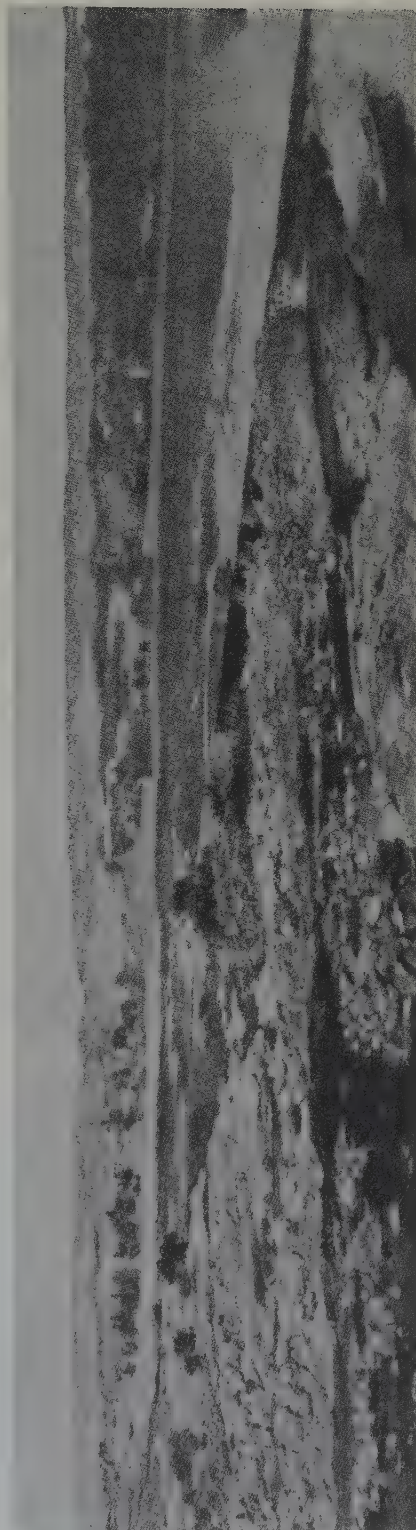

FIGURE 1a. Exposures of crystalline rocks on the Nile at Aswan.

are developed in the Aswan area: biotite gneiss and crystalline schist, and hornblende gneiss cut by granodiorite and coarse to fine-grained granite. Younger formations in the Aswan area include, according to him, andesite dikes cut in turn by dikes of an alkalic series — camptonites and bostonites.

Another large area of development of extrusive rocks in Egypt is the Eastern Desert province between the Nile valley and Red Sea (Figure 1). Here, a chain of highlands trends almost meridionally, with peculiar geomorphology and high summit elevations in the vicinity of the pass.

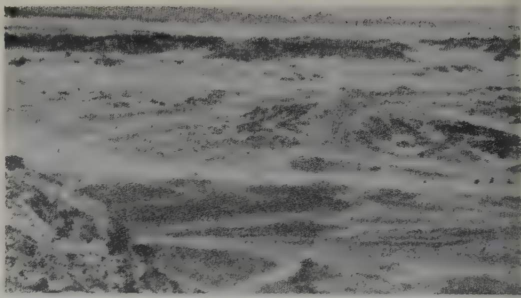

FIGURE 3. Mountain-desert landscape (Gebel El Nakad, Eastern Desert).

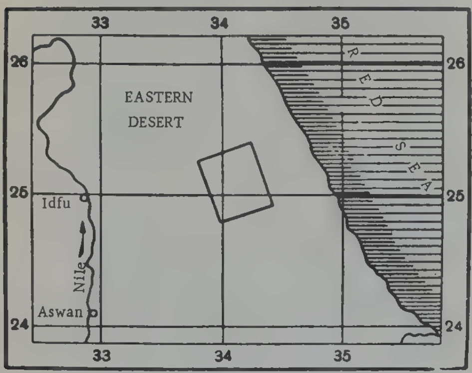

FIGURE 1. Eastern part of Egypt. The area of principal field trips in the Eastern Desert is framed.

The peculiarity of this province has been brought about by its change to desert conditions before the peneplanation process has been completed. This part of Egypt gives a definite impression of mountain country dying. Mountains many with sharp peaks, are separated by level surfaces of sand, the products of their disintegration (Figures 2 and 3). Barely perceptible on these sandy expanses are wadis, the valleys of former rivers (?), now almost fully sanded up. Such a landscape has its advantages: one can drive over it in a car, in any direction. In the two days out in the desert, we succeeded in travelling about 500 km. The black top road from Idfu railroad station in the Nile valley to Marsala settlement on the Red Sea shore is oriented parallel to innumerable automobile tracks running in all directions over sands of the Eastern Desert.

The central parts of relict mountain ranges of the Eastern Desert are formed by disturbed metamorphic rocks cut by assorted extrusives.

The general aspect of the igneous complex of the Eastern Desert is rather reminiscent of igneous associations of a folded province which has gone through a geosynclinal development.

According to E. M. Shazly and M. Mamdouh Hamada (1954), the following pre-Carboniferous

FIGURE 2. Mountain massif in the sands of the Eastern Desert.

probably mostly Precambrian associations are involved in the structure of the Gebel Madargog area of the Eastern Desert: 1) metamorphic rocks, 2) serpentine and associated rocks, 3) granodiorite and diorite of the gray granite complex, 4) pink granite, 5) acid dikes and veins (aplite, microgranite, felsite, and quartz veins), and 6) andesite and basalt dikes.

Up to now, Egyptian geologists have mapped, during systematic geologic surveying of the Eastern Desert, outcrops of trachyte and intrusions of nepheline syenite.

Thanks to the cooperation of the Egyptian Geological Survey (Professor Higazy, Director) and to the kindness of Mr. M. F. Ramly, Chief of a surveying party, I succeeded in getting acquainted with and in collecting material representing various crystalline rocks of the Eastern Desert, including the newly-discovered trachytes and nepheline syenites.

The age of both the Aswan and Eastern Desert granites have not been determined with adequate certainty.

H. M. E. Schürmann, in his paper on the Precambrian of the Suez area of Egypt [14], identifies among Precambrian rocks the proto-Archean basement gneiss, Middle Proterozoic Shaitian granite of the first series, and upper Proterozoic Cattarian granite of the second series.

Professor R. A. Higazy and H. M. Wasfy, in their Notes on the Age of Egyptian Granites [8] identify two age types: 1) ancient Shaitian granite and 2) late Precambrian Cattarian granite. According to them, the latter granite group is widely distributed in Egypt, with pink granite its typical representative.

These authors correlate their granite groups with various granites of Morocco, Bechuanaland, Sudan, Gold Coast, India, and Australia. Specifically, they correlate the ancient Shaitian granite with those of Tazenacht, Morocco, and Delhi, and with Indian granites of middle Archean age; the Cattarian granite they correlate with Indian granites and younger granites of Nigeria and Sudan.

The absolute age of Tazenacht granite was determined by A. Holmes as 1860 million years ± 120 million years. Consequently, according to R. Higazy, the age of the Shaitian granite of Egypt is probably about 2000 million years. The Cattarian granites are younger, but still Precambrian; their age range is 620 to 900 million years.

I also succeeded, in the company of Professor E. M. Shazly, in inspecting basalts exposed on the road to Alexandria, 13 km out of Cairo. The basalts rest on fossiliferous Eocene beds and are overlain by the Miocene.

BRIEF PETROGRAPHIC DESCRIPTION OF TYPICAL ROCKS IN PARTS OF EGYPT VISITED

The Aswan area. Coarse porphyritic pink granite of Aswan has long been known as excellent building material. Still standing are the ancient quarries from which large granite blocks were taken. As early as the IV Dynasty (over 5000 years ago), the Aswan quarries produced ornamental stone for temples and palaces. The Karnak Obelisk, about 30 m high, was set up at Luxor in the XVIII Dynasty period (Figure 4). Aswan granite was used for many monuments of ancient Egyptian art (Figure 5).

Externally, typical Aswan granite is fresh-looking, pink, with a coarse-grained gneissoid texture. It displays a definite linear orientation of elongated microcline. The porphyroblasts of microcline are prismatic, reaching 3 x 2 cm. Black biotite, quartz, and plagioclase are developed in interstices. The grains of these minerals are much smaller, usually 6 x 8 mm. Biotite occurs in bands, which emphasizes the gneissoid appearance of the rock. Its texture is porphyritic.

The component minerals are microcline-microperthite, plagioclase-oligoclase, quartz, biotite, hornblende, sphene, apatite, and magnetite, with secondary epidote and calcite. Microcline-microperthite replaces plagioclase, which is quite noticeable in thin sections where obviously corroded plagioclase forms uneven resorbed inclusions in microcline.

Likewise, biotite, younger than plagioclase in terms of time of crystallization, appears in biotite as inclusions. Biotite, too, is replaced by microcline.

Plagioclase inclusions in microcline are of two types: 1) perthite growths commonly forming albite-oligoclase bands; and 2) resorbed relicts of the replaced plagioclase. It often happens that isolated relicts, specks of unreplaced plagioclase, show a single orientation.

Formed in brownish pelitic relict-grains of plagioclase, at their contact with microcline, are narrow reaction fringes, 0.1 mm thick, of transparent albite-orthoclase. Many near-contact plagioclase grains are strewn with vermicular growths of secondary quartz (mirmekite). In the replacement of plagioclase by microcline, the microcline sometimes shows a relict structure of polysynthetic twinning preserved from oligoclase. The unaltered plagioclase-oligoclase is twinned according to the albite rule.

Biotite is pleochroic: olive-green along γ

FIGURE 4. Karnak obelisk of Aswan granite, Luxor.

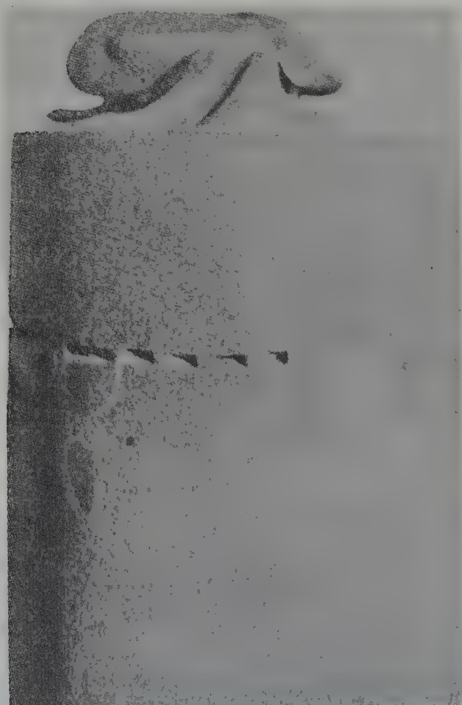

FIGURE 5. Scarab cut on a monolith of Aswan granite.

and yellow along α. Isolated grains of hornblende are deep blue-green. Quartz is fractured, with nebulous extinction. Accessory minerals are altered orthite, spene, apatite, zircon, and magnetite. Secondary sossurite is formed on plagioclase; chlorite on biotite; epidote and calcite occur in veins which cut the microcline, as well.

The quantitative mineral composition of porphyritic granite is given in Table 1.

Microscopic studies show that microcline has been formed in granite metasomatically, in an already consolidated rock. Similar examples of a later formation of microcline are numerous in Soviet Union granites as well as in those elsewhere. A replacement of oligoclase by microcline in Precambrian Umm Saolatit — El Hisinat granite has been described by Egyptian geologists M. S. Mansour, F. A. Bassyumi, and D. M. Ol-Far, [11a].

Excellent exposures of granite (Figure 6) are seen on the bank of the Nile at the Cataract Hotel. They show a spessartite dike which appears to have been formed, as in many other intrusions of porphyritic granites into granitoids, prior to the microclinitization stage [1, 2]. Idiomorphic porphyroblasts of microcline occur in the peripheral part of the spessartite vein, as well as in the enclosing granitoids.

Exposed in the area of the proposed new Aswan dam are crystalline schist and biotite gneiss cut by numerous veins of aplitic and pink fine-grained granite. These rocks have the normal composition of alaskite granite: quartz (cataclastic), oligoclase (partly sossuritized), microcline-microperthite, biotite (in small amounts), muscovite (contemporaneous with microcline), and accessory apatite, magnetite, and zircon. Quantitative composition of these granitoids is given in Table 1. Absolute-age determination data are listed in Table 2.

Eastern Desert (central part of the mountain province in the area of road from Idfu station to Marsala). During my field trips in the company of M. F. Ramly, I got acquainted with the main igneous featurea of this area. My observations have resulted on the whole in the same conclusions on the sequence of igneous formations as those accepted by Egyptian geologists.

The most ancient granite of Egypt, the Shaitian, does not occur in the area of our field trips; however, specimens of this granite and of the aplite which cuts it were kindly presented to me by M. F. Ramly. My specimen of the Shaitian granite is a coarse-grained gneissic granite with oriented coarse plates

TABLE 1

QUANTITATIVE MINERAL COMPOSITION OF SOME EXTRUSIVE ROCKS IN THE EASTERN DESERT AND THE ASWAN AREA (EGYPT)

Specimen Number	Location of Extrusive Rocks	% by volume										
		quartz	plagioclase	k-Na-feldspar	biotite	muscovite	hornblende	nepheline	feldspatite (nosean), etc.	Ore and accessory Minerals	secondary	total
1	Aswan porphyritic granite	33.0	25.1	33.0	8.4	—	0.1	—	—	0.4	—	100.0
65/59	Pink even-grained granite	28.3	32.7	36.5	—	2.5	—	—	—	—	—	100.0
66/59	Aplite, same place	32.1	38.7	28.1	0.5	0.5	0.1	—	—	—	—	100.0
61/59	Shaitian plagio-granite gneiss	35.0	48.6	—	8.0	2.0	—	—	—	1.0	5.4	100.0
62/59	Aplitic gneiss (cutting the preceding)	42.2	47.6	—	—	7.0	—	—	—	—	3.2	100.0
60/59	Gray granodiorite	24.4	53.6	—	10.0	—	10.0	—	—	1.0	1.0	100.0
42/59	Trondjemite	39.8	54.7	—	2.6	—	2.9	—	—	—	—	100.0
36/59	Subalkalic gneissic granite ("psammitic" gneiss)	35.6	29.4	25.3	3.2	—	6.5	—	—	—	—	100.0
33/59	Plagiogranite	37.0	59.3	—	—	—	—	—	—	—	3.7	100.0
20/59	Pink granite	39.6	29.5	38.5	1.9	—	—	—	—	—	0.5	100.0
52/59	Nepheline syenite	—	18.9	33.9	0.9	—	12.9	21.5	10.9	0.5	0.5	100.0

FIGURE 6. Granite outcrops at Aswan.

of somewhat chloritized biotite. In composition, this rock is a plagiogranite (quartz, oligoclase, biotite, and accessory minerals); it is strongly metamorphosed. Its plagioclase is deformed and sossuritized; the quartz is cataclastic. Epidote, zoisite, and apatite are present in considerable amounts (see Tables 1 and 2).

Aplite which cuts the Shaitian gneissic granite has been metamorphosed to the same extent as the enclosing granite. In composition, it is gneissoid plagioalaskite with a porphyritic texture. The primary oligoclase has been considerably metamorphosed. Epimagmatic minerals are developed in this rock: titanite, epidote-zoisite, and muscovite.

From the microscopic data and a partial chemical analysis (for alkalies in the determination of absolute age), it can be inferred that these granitoids belong to the sodium branch, i. e., they are plagiogranites. For lack of field observations, their association with other rocks cannot be ascertained. Plagiogranite associated with serpentine rocks in the area of a former asbestos mine is less metamorphosed. The absolute age of my specimen of the Shaitian gneissic granite, determined by the K-Ar-method, turned out to be 600 million years. Results of the absolute-age determination for some Egyptian rocks will be considered in more detail below.

According to our observations, corroborated by those of M. F. Ramly, the enclosing rocks of intrusions in this area are phyllitic schist and schistose albitophyre and their tuff in a metamorphic sequence.

The metamorphic sequence is cut by intrusions of serpentine rocks, gabbroid dikes, and sills of plagiogranite and plagiopegmatite. Such an association is, as a rule, typical of igneous activity in geosynclinal provinces.

It should be noted in this connection that gneisses cropping out at Gebel-Megaf and regarded by local geologists as psammitic should be regarded rather as gneissoid extrusives of the alkalic granite type. They are characterized by albite plagioclase cataclastic quartz, fresh microcline (latticed), and a strongly metamorphosed alkalic amphibole (Table 1). Judging from the absolute-age data, these rocks are rather plagio-gneisses which have undergone K-metasomatism.

In areas affected by granite intrusions, schist of the metamorphic sequence has been altered to micaceous crystalline schist injected with quartz and felspathic material.

Granite rocks with which we had time to get acquainted are represented by gray granodiorite forming sizable massifs, and pink granite, usually porphyritic, with xenoliths of older granitoids. These granites (metasomatic microcline) are associated with muscovite-microcline pegmatites and small bodies of alaskite microcline granite.

In the area of the Gebel Nogros gold mine, pink porphyritic granite carries xenoliths of greisenized plagiogranite and red granite porphyry with a low content of Na-orthoclase. A study of granite with these xenoliths reveals that they are typical microcline granite probably of a complex origin rather than having been formed in the single crystallization stage of a magmatic melt. The original plagiogranite type

TABLE 2[1]

Specimen No.	Location	Identified			Age in Million Years $\lambda_K = 5.50 \cdot 10^{-11}$ Years -1 $\lambda_\beta = 4.75 \cdot 10^{-10}$ Years -1
		K	Na	Ar-Hm $m^3/gr.$	
52/59	Vein of fine-grained nepheline syenite in the Gebel-Abu-Khuruq nepheline syenite intrusion.	3.80	6.57	0.006	40
51/59	Intrusive nepheline syenite (Gebel Abu Khuruz)	4.29	6.78	0.011	55
56/59	Granosyenite in the periphery of a nepheline syenite massif (same locality)	3.79	2.89	0.011	75
55/59	Same: pegmatoid granosyenite (same locality)	3.26	2.84	0.011	80
46/59	Trachyte (Gebel El Nuhud-north)	4.06	4.46	0.014	78
40/59	Bostonite (Gebel Um Kebesh)	3.90	3.59	0.049	290
29/59	Camptonite	1.54	2.16	0.018	300
33/59	Plagiogranite affected by camptonite	0.74	2.03	0.009	285
65/59	Vein pink granite in crystalline schist at Aswan	4.36	2.59	0.074	410
65/59	Aplite, same locality	4.16	2.84	0.072	410
42/59	Trondjemite (in the area of bostonite dike 40/59) (Gebel Un Kebash)	0.55	3.27	0.011	450
36/59	Subalkalic gneissic granite ("psammitic gneiss) (Gebel Megaf)	3.31	2.87	0.062	430
35/59	Microcline pegmatite near a camptonite dike (cut by camptonite)	7.00	1.26	0.149	340
20/59	Pink granite (Gold Main Gebel Nogros)	3.25	2.61	0.066	460
17/59	Xenolith? Schlieren? (same locality)	2.80	3.00	0.048	420
3/59	Microline from a pegmatite vein (Wadi Rod Um El Farag)	9.38	2.26	0.200	470
2/59	Muscovite (same locality)	8.62	0.52	0.234	600
48/59	Pegmatite near trachyte dome (46/59) (Gebel El Nuhud)	7.62	1.49	0.200	590
61/59	Shaitian gneiss granite	1.00	2.00	0.027	590

[1]At the I.G.E.M. Absolute-Age Laboratory, L.L. Shanin determined the age of specimen 2/59 as 600 million years, and porphyritic granite from Aswan as 470 million years.

ock was subject to metasomatic alterations ccompanied by the formation of quartz and nicrocline-perthite porphyroblasts, as witness lso the presence of two generations of biotite, ne of which is chloritized.

The younger igneous formations in the area f the Eastern Desert visited are represented y the Alkalic rock group. Identified among them is the older group of subalkalic dike rocks, camptonites and bostonites, differing in the degree of their metamorphism and in absolute age from trachytes and nepheline syenites of the younger group.

Camptonites, macroscopically black dense rocks, form dikes up to 1.5 or 2 m wide and several hundred meters long. They have a

porphyritic texture with small porphyroblasts of titanium augite. Their groundmass is formed by a finely tabular brownish albite, barkevikite, with an abundance of ore grains. The numerous amygdules are filled with chlorite-serpentine and calcite. In mineral and chemical composition, this rock belongs to the sodium branch of the subalkalic basic group. Camptonites carry xenoliths of plagiogranite. Contacts of camptonite with microcline pegmatites are tectonic. In Gebel Um Kebash, red-brown vein rocks, which Egyptian geologists call bostonite, cut the gneiss. They are fine-grained, fully crystalline, essentially feldspathic rocks, with the feldpar represented by a brownish albite-oligoclase and to a smaller extent by orthoclase. Developed in interstices between feldspars are massive chlorite and considerably altered biotite, with a finely dispersed ore mineral. Isolated segments of this rock have been replaced by calcite.

Trachytes form a dome (Figure 7) intrusive into the Gebel-El-Nuhud gneiss. These are dark fine-grained rocks, essentially feldspathic, with an abundant development of iron oxide in interstices between the feldspar grains. Feldspars are represented by prisms of albite-oligoclase and K-Na-feldspar.

grained dense nepheline syenite, more melanocratic than the intrusive one.

In the upper part of the slope, the nepheline syenite intrusion is overlain by a mass of fine-grained syenite spheres cemented by the same material. The contact between the intrusive and spheroid nepheline rocks is sharp.

The sphere-forming rocks are fine-grained, with a porphyritic texture. The porphyroblasts are anorthoclase with corroded fragments of a single nepheline grain. Developed in the groundmass are feldspar, highly ferruginous biotite, and aegirine. Its melanocratic fraction is about 40% (by volume).

The enclosing rocks along the periphery of the intrusive nepheline syenite mass contain veins of pegmatoid rocks of anorthosite and quartz with a low biotite content and alkalic nornblende. Also present are fine-grained granosyenites which field geologists called "rhyolites." These alkalic granosyenites are cut by a coarse-grained pegmatite of anorthoclase and alkalic hornblende with a late precipitation of quartz.

The alkalic granosyenites and associated

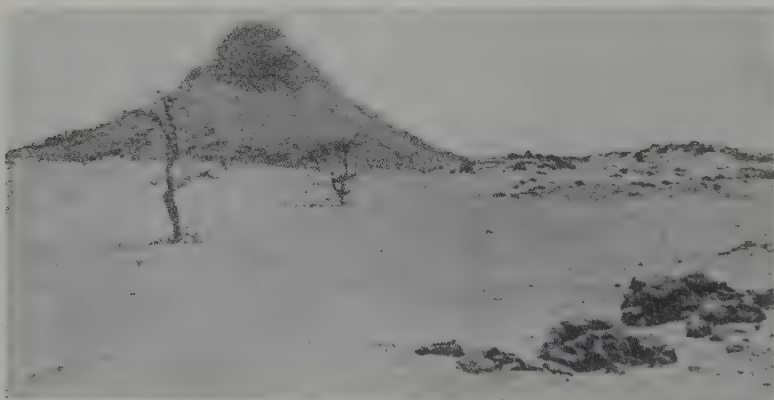

FIGURE 7. Trachyte dome Gebel-El-Nakad (Eastern Desert).

Outcrops of nepheline syenite intrusions have been observed in Gebel Abu Khuruq.

Intrusions of nepheline syenite proper are exposed in the lower part of the slope. These are coarse-grained rocks, light gray with isolated pink segments of cancrinite, a gray feldspathoid of the sodalite group with aggregate concentrations of dark minerals. For the quantitative mineral composition of the alkalic group of rocks see Table 1.

Intrusive nepheline syenites are cut in their upper part by a gently dipping vein of a fine-

pegmatites preceded the intrusion of nepheline syenite. They are exposed among rocks enclosing the latter.

THE ABSOLUTE AGE OF EXTRUSIVE ROCKS IN EGYPT

My collection of Egyptian rocks from the Eastern Desert field trip and from the Aswan area was shipped to me by the National Research Center, Cairo, for which it is my pleasant duty to thank Professor R. Tourky, its Director.

Some of the samples were used in the

determination of absolute age by the K-Ar-method.

Radiogenic argon was determined in the Age Laboratory, Daghestan Affiliate of the U. S. S. R. Academy of Sciences (Professor Kh. I. Amirkhanov, S. B. Brandt, and Ye. Bartnitskiy); alkalies were determined by A. A. Vaskovskiy in the laboratory of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, AS U. S. S. R. I am grateful to all of them for their assistance in my work.

The lack of time during the field trips made it impossible to collect enough material for isolation of monomineral fractions in amounts adequate for an age determination. For that reason, most determinations were made on whole rock, with some determinations done on minerals of pegmatite veins (K-Na-feldspar, muscovite).

The figures so obtained show that the age determination by the K-Ar-method on whole rock is quite feasible at the first stage of study, provided care is taken in geologic and petrographic analysis, as I have stated before [1, 2]. Such determinations are sufficiently reliable for younger formations, not subject to the effect of later, superimposed igneous bodies.

Such data are also reliable for the age determination of plagiogranite rocks without K-Na-feldspar. In determining the age of essentially microcline granitoids using whole rock, we may come up with a figure for K-Na-feldspar itself or for the period of metamorphism.

By correlating results of absolute age determinations given in Table 2 with the geologic and petrographic data, and considering the state of knowledge of igneous activity in Egypt, we are justified in designating the following age groups of extrusive rocks, always being mindful of the problems arising in this connection.

The first group of the most ancient rocks undoubtedly includes gneissic plagiogranite, the so-called Shaitian granite, samples of which were given us by geologist M. Ramly.

The age of this granite is the same as the age of muscovite from the Wadi Rod Um El Farag pegmatite vein. Muscovite from that vein (specimen 2/59) is considerably smashed and obviously metamorphosed. However, pink coarsely clastic microcline from that vein turned out to have an age of 470 million years, which is the age of the predominant Cattarian-type pink granite. Whether this is due to a loss of radiogenic argon or to superposition of K-metasomatism during a Cambrian igneous stage will be determined by a broader and more detailed absolute-age study. It should be noted at the same time that an age of 590 million years, almost identical with that for the above-named muscovite (specimen 2/59), was determined for K-Na-feldspar (specimen 48/59) from Gebel El Nakad, microscopically different from microcline (specimen 3/59) in the Wadi Rod Um El Farag.

Along with the microscopic difference in ancient white K-Na-feldspar (specimen 48), its K/Na ratio is 5:1, while it is 4:1 in younger pink microcline (specimen 3).

All this suggests a stage of K-metasomatism connected with the intrusion of Cattarian granite, 400 to 450 million years ago.

The age of this first group is most likely Proterozoic, close to its boundary with the Cambrian. Possibly belonging to this group also are the red plagiogranite (specimen 33/59) in a xenolith in the camptonite dike; and pegmatite (specimen 35/59) with K/Na = 5. 5 for its K-Na-feldspar, in contact with the same camptonite.

The second group includes pink granite of the Cattarian type. Formed at the same time were porphyroblasts of the Aswan porphyritic granite. An age of 450 to 470 million years was obtained for normal pink granite with biotite; and 410 million years for aplite and alaskite, including some from the Aswan area. Thus the formation of pink granite took place more probably in the Ordovician.

It appears that the formation of pink granite was preceded by an intrusion of gray granite whose age is unknown, as yet, and of fresh-looking trondjemite whose age has been determined at 450 million years. This last figure will have to be verified because of the low K-content in the rock.

It is also important to check on the geologic assumption that ultrabasic rocks in the area of the abandoned asbestos mine, too, belong to the same association, being older than the granodiorite and trondjemite. Also of interest are the geologic relations of these ultrabasics to gneisses and pegmatites of the Gebel-El-Nakad-type gneisses. It is possible that ultrabasics of that area are younger than the latter.

Assigned to the third group may be dikes of subalkalic camptonite and bostonite, about 290 million years old, which corresponds most likely to the Devonian. Intrusive massifs similar to them in petrographic aspect and age are unknown as yet from that part of Egypt. It is not impossible that these subalkalic dikes are associated with the last stage of the formation of a Cambrian-Ordovician igneous complex displaying a similarity to rock associations which originate in the process of evolution of a geosyncline.

Belonging quite definitely to the fourth group are: a) domes of the extrusive Gebel-El-Nakad

(north) trachytes, 75 to 80 million years old; b) subalkalic granosyenite of the same absolute age; and c) the youngest intrusions of nepheline syenite, 55 and 40 million years old. This Cenozoic (Tertiary) igneous activity in the Eastern Desert took place under platform conditions.

These data on the absolute age of some rocks from the Eastern Desert and the Aswan area, although preliminary, are very revealing in understanding the evolution of igneous activity in Egypt and for general problems of petrology.

The figures cited suggest a Proterozoic or lower Paleozoic (Cambrian-Ordovician) igneous activity in the northeastern part of Africa (Egypt), which is in some contradiction to current geologic concepts. For that reason, the problem of the absolute age of Egyptian rocks requires, of course, further study. At the same time, the probability of Paleozoic and Mesozoic igneous formations within the African shield is corroborated by geochronologic data on Africa, cited by A. Holmes and L. Cahen [9].

Those authors give the following figures (in millions of years) for the first group (up to 485 million years old):

1. Kimberlite (Union of South Africa), by the helium method 58

2. Melilite basalt from the Spiegel River Farm 51

3. Trachyandesite (Zambezi, Angola) . . 90

4. Galena from Dzhebel Gostag, Algiers, by total lead, according to the authors 80

Within this group, the authors also cite figures of 255 million years for the Befarfar (Madagascar) samarskite, and 370 million years for the Mablads (Morocco) galena.

These authors assign to the second group the following assorted minerals and rocks of Africa (age in millions of years):

1. Uraninite from Bemasandro, Madagascar 480

2. Thorianite from Madagascar 480 and 490

3. Samarskite from Kenya 480

4. Zircon from the Keptuan granite . . . 510

5. K-feldspar from Kenya . . . . 550 (± 50 million years) from individual determinations . . . . .485 to 550

6. Zircon from gneissoid nepheline syenite of Tambone from four specimens, 515, 569, 543 and 523, respectively

7. Monazite from an albite-aegirine rock, same locality 542

L. Cahen, A. M. MacGregor, and L. T. Neil also cite a table [5] of age determinations by radioactive methods, for some Precambrian formations of Africa. The youngest in this table, 590 million years old, is the Morogoro uraninite from Tanganyika. Its age is determined by the lead isotope method. Of the same age (600 million years) is pitchblende from Shinkolobwe, Katanga. The age of "davidite" from Mozambique, determined by the lead method without isotopes, is estimated at 565 million years.

Our own data on the absolute age of Egyptian rocks (Table 2), coincide to a certain extent with those of A. Holmes and L. Cahen [5] for African minerals, and suggest an evolution of igneous activity in that part of the African continent, which was more complex than is now thought.

The basement of the ancient folded province trending meridionally in the northeastern part of that continent (the Eastern Desert) is formed of Proterozoic crystallines. Later on, in the Cambrian and Ordovician, a geosyncline was formed there; in the process of its evolution, a series of basic extrusives, ultrabasics, and plagiogranite-trondjemite was formed. This series corresponds to the geosynclinal stage proper. The next series of pink granitoids of the Cattarian type with pegmatites and aplites is characteristic of a transitional stage preceding the platform stage.

Small manifestations of Caledonian igneous activity in this platform type structure are represented by dikes of subalkalic camptonite and bostonite, 290 to 300 million years old.

Cenozoic igneous activity in the Eastern Desert is represented by Tertiary extrusions of trachyte (70 to 80 million years old) and intrusions of nepheline syenite (40 to 55 million years old). The alkalic part of Cenozoic igneous activity in Egypt is interesting in that we find in it new evidence of a regular development of planetary igneous activity.

Tertiary igneous activity in many regions of Africa, Asia, and Europe is characterized by a specific association of extrusive rocks which include subalkalic and alkalic varieties formed in Early Tertiary time (up to the Miocene). It must not be forgotten that, besides the Egyptian example, the same igneous epoch embraces alkalic and subalkalic rocks of the Caucasus, east Siberia, Sakhalin, central Europe, and South Africa.

Specifically, according to G. P. Bagdasaryan,

intrusions of nepheline syenite in Armenia are 40 million years old; according to my data, the north Caucasian trachytes are 60 to 70 million years old; and alkalic rocks of Silesia are Oligocene, according to K. Smulikovskiy. According to I. V. Belov, the trachybasalt formation of eastern Siberia is Tertiary. The same is true for alkalic intrusions on Sakhalin and, according to the latest data, for subalkalic rocks on the islands of Mull and Skye (Scotland). But the reason for Early Tertiary alkalic igneous activity is that it corresponds to the culminating stage of a definite cycle of igneous activity in the interior of the earth. Similar, but not identical differentiation of igneous rocks developing during culminating stages of periodical igneous cycles is typical of older epochs of the earth's history, as well.

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A GROUP OF PERMIAN VOLCANIC NECKS IN THE KATU MOUNTAINS (DZHUNGARI ALATAU)[1]

by

M. P. Rusakov and G. M. Fremd

Predictions of a wide distribution of crater facies of Permian extrusives along the south slopes of the Dzhungari Alatau, made on the basis of the 1957 study in the Arkharla and Chulak mountains [4], were fully confirmed in the summer of 1958 by the discovery of a group of volcanic necks in the Katu Mountains.

This discovery of volcanic necks and associated crater facies, previously unknown in the Dzhungari Alatau, is of great theoretical and practical interest. They reveal a better picture of late Paleozoic volcanism in southeastern Kazakhstan, thereby shedding a somewhat different light on the geologic history of that country; moreover, these extrusions account fairly convincingly for the wide distribution of secondary quartzite copper, gold, and polymetallic mineralization in extrusive sequences, not connected with intrusive rocks which are either absent or poorly developed in a number of areas of the Dzhungari Alatau.

Crater facies of Permian extrusives may be regarded as an important criterion in the search for industrially useful metallic and nonmetallic minerals in that area of Kazakhstan.

GEOLOGY OF THE KATU-TAU

The Katu massif, the southernmost in the Dzungari Alatau system, is also the most peculiar, first of all in outline and morphology. In plan, it has the shape of an equilateral triangle whose sub-latitudinal base cuts it off from the Bashchiyak trough in the north (Figure 1) while its apex protrudes considerably southward toward the Ili valley. This peculiarity in outline, coupled with the absence of a distinct topographic divide, corresponds fully to its geomorphic features: there are no mountain ranges and valleys arranged in a single structural plan. Rather, there is a haphazard piling up of peaks, small sopkas, and tectonic valleys in-between, trending in various directions. In the Katu mountains, more than anywhere else, there is striking evidence of the importance of block tectonics in forming this mountain system.

As seen from an airplane, the Katu is a mountain plateau consisting of many cirques, rocky peaks (sopkas), and amphitheaters. Not uncommon in the centers of these cirques are isolated higher peaks reminiscent of volcanic necks. The mountains are separated by numerous valleys whose tectonic origin is suggested by their rectilinear trend, narrowness, and steep slopes. The origin of such forms in this area is hardly explicable by stream or glacial erosion alone. Predominant are meridional, sublatitudinal, and the northeasterly trends.

The interior structure of the massif could not be more in harmony with its morphology. The importance of block tectonics is shown with outstanding clearness in natural cross sections several kilometers long, exposed in the southwest face of the massif. A repetition of monoclinal sequences and members of lava flows alternating with pyroclastics, gently dipping to the south and less commonly to the north, is seen over long distances. Such structural cross sections are due exclusively to radial displacement of individual blocks of formerly nearly horizontal Permian extrusive pyroclastic rocks.

The structural plan is modified somewhat only around individual eruptive centers where, as will be described in detail below, the beds were evidently uplifted by eruptive forces to form peculiar domal structures of Tertiary age and recent volcanoes of southeastern Asia [1, 2].

The Katu volcanic and sedimentary sequences are typical Permian-Carboniferous continental formations. However, there are no definite boundaries between rocks of these two systems; nor are there angular unconformities, fossiliferous horizons, or any other criteria for an unequivocal differentiation.

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[1]Gruppa permskikh vulkanicheskikh apparatov v gorakh Katu (Dzhungarskiy Alatau).

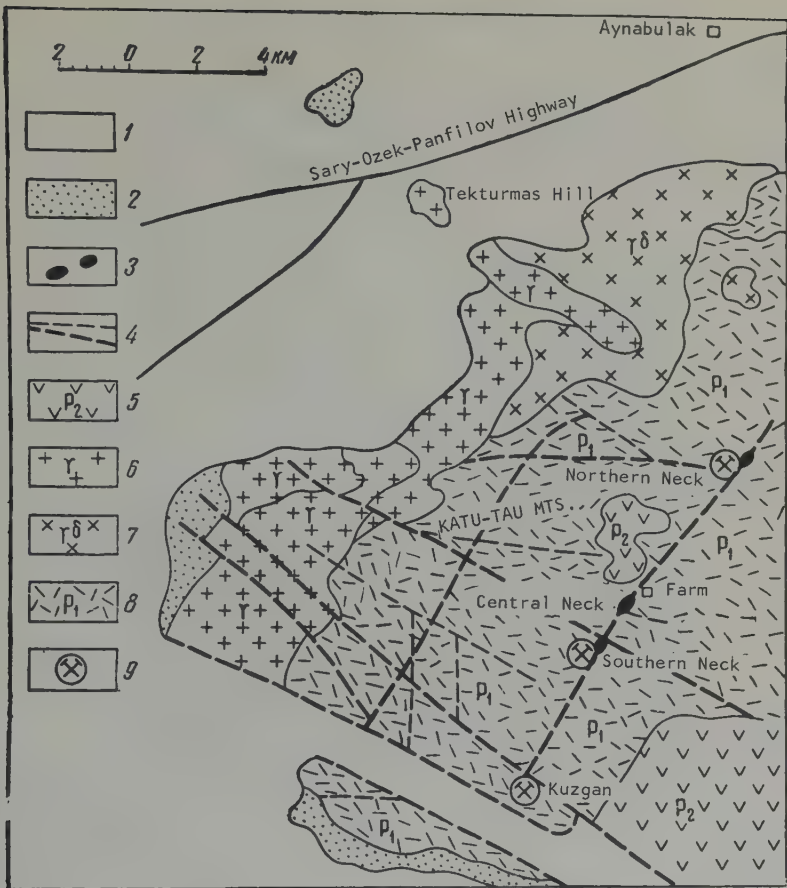

FIGURE 1. Generalized structural geologic map of the western part of the Katu mountains.

1) Quaternary and recent deposits; 2) Tertiary deposits; 3) necks of Permian extrusive felsite; 4) fault traces; 5) Upper Permian extrusive formations; 6) late Variscan granite; 7) Variscan granodiorite; 8) Lower Permian (locally Upper Carboniferous) extrusives; 9) showings of copper mineralization.

The current concept [3] of a Late Carboniferous age of this sequence (acid extrusives and pyroclastics), based on its correlation with sequences of that age located on the northern slopes of the Dzhungari Alatau, appear to us as unconvincing. It is more correct to regard it as Lower Permian, inasmuch as its extrusives and andesitic pyroclastics with tuffaceous sandstone have been traced far to the south where the development of Permian deposits is not subject to any doubt. The Permian age of this sequence is also corroborated by the fact that volcanic necks which cut it are represented by rocks often very similar geochemically to the Katu extrusive sequences.

PERMIAN VOLCANIC NECKS IN THE KATU MOUNTAINS

Volcanic necks described below are located in the central part of the Katu massif, in the area of development of Permian and some Upper Carboniferous extrusive sequences which form a system of interbedded lava flows and thin tuffs of an andesite and andesite-dacite composition.

The northern, central, and southern volcanic necks identified by their position.

1. Northern Neck

This neck, the first to be discovered in the Katu mountains (August, 1958), is located 10 km southeast of Aynabulak settlement, at the 102nd kilometer of the Sara-Ozek-Panfilov highway. The neck stands in the center of a wide cauldron, about 3 to 3.5 km in diameter.

Morphology. As seen from a distance of one kilometer to the south, the volcanic neck looms

up as a solitary monolithic peak standing out among smaller sopkas. Its peculiar structure is marked both by its monolithic aspect and vertical flow-line banding which is especially pronounced in the oblique rays of a rising or setting sun. This banding is caused by columnar parting developed along the flow structure of lavas.

In plan, the neck is somewhat elongated to the northeast and cut off in the north and south by narrow tectonic valleys. Its length at the base is about one kilometer; it is about 600 m wide. Its top is a comparatively narrow crest trending N35° E, broken up by narrow rocky gorges.

Petrographic description of rocks. In composition and texture, the neck rocks are plagiorhyolite. Macroscopically, they are fresh-looking to slightly altered brick-red rocks, with a cryptocrystalline groundmass and a more or less conspicuous flow structure. Hydrothermally altered quartzitic varieties, most common in the neck, show up distinctly because of their light-gray color; they, too, have a flow structure.

Seen under the microscope, this rock consists of a microfelsitic groundmass with a flow structure and rare phenocrysts of plagioclase (andesine). Phenocrysts, conspicuous in some thin sections, are streamlined by the groundmass, which indicates their crystallization in an earlier intratellurian period.

The microfelsite groundmass consists of microlites, glass, and mostly undifferentiated quartz and feldspathic material, also ore minerals in fine dispersion. The flow structure is quite noticeable under the microscope by the alternation of bands of recrystallized material and brown glass partly altered to a kaolinitic semi-transparent mass.

Hydrothermal alteration in rocks of the northern neck are very conspicuous under the microscope. We have not observed fresh varieties unaffected by hydrothermal alteration in any of the numerous thin sections. Even the macroscopically fresh, seemingly well-preserved rocks revealed under the microscope definite traces of silicification, kaolinitization, ane alunitization, less commonly epidotization, chloritization, and other types of hydrothermal alteration.

Kaolinite is developed in the groundmass in thin scales forming dense aggregates which stand out because of their yellow-white color in reflected light. In addition, there are coarse tabular crystals of this mineral, often in simple twins with a well expressed direct extinction and a positive sign. In slightly hydrothermally altered rocks, the kaolinite content reaches 15 to 20%. In strongly altered rocks, changed to secondary quartzite, the kaolinite content is as high as 65%.

Hydrothermal secondary quartz is usually represented in light-colored rocks by webfoot-shaped fine grains developed in a drab-gray kaolinite mass. The optical constants of quartz are readily determined for isolated coarser grains but very much less easily for the fine-grained quartz-kaolinite mass.

Alunite occurs only in isolated scales with a direct extinction, a negative sign, and a yellow interference color.

Kaolinization and silicification are the two most highly developed processes. Alunitization, epidotization, and chloritization are much less developed.

The epidotization process consists of replacement of plagioclase phenocrysts by individual epidote-zoisite crystals or aggregates. Considerably less common are fine-grained accumulations developed in the groundmass.

Chlorite forms the finest scaly aggregates, most likely replacing biotite or isolated segments of glass.

Flow structure of the neck. Numerous systematic measurements of flow structure have shown that in the peripheral part of the neck, the flow structures in lava coincides with the somewhat sublatitudinally elongated outline of the neck and closes at its western and eastern ends. In the central part of the neck, the flow structures are haphazardly oriented, with a sublatitudinal trend predominant. Dips of flow bands, both along the periphery and in the central part, approach the vertical, directed as a rule from the periphery to the center. As pointed out before [4], such orientation of the flow structure is in fair accord with our concept of the mechanism of the formation of necks. A viscous rhyolite magma rose in the central crater, as if squeezed out of a tube. In so doing, it formed a flow structure repeating the outline of the volcanic crater, with dips toward the center of its widened mouth. Originating along with the main flow structure were local eddies reflected in a very bizarre pattern.

The more definite and better oriented flow structures developed along the periphery of the lava column, because of the latter's higher viscosity and the orienting effect of the crater's walls, while the more haphazard orientation was confined to the central and more mobile part of the column.

The columnar parting in plagiorhyolite, closely related to flow structure, is represented everywhere on the neck slopes by a multitude of polygonal blocks elongated parallel to one another and to the flow structure (Figure 2).

FIGURE 2. Vertical flow structure and parting in extrusives of the northern neck, Katu Mountains.

Only their outer faces are well defined while the inner ones have grown together and are less distinct. In its strict duplication of the flow structure, the parting gives a good idea of the neck structure, the nature of flow, the eddying of the lava, etc.

The enclosing rocks, their petrography and contact with the neck rocks. The volcanic centers are located in a large field of development of Upper Carboniferous — Lower Permian extrusives; tuffs, and individual members of tuffaceous sedimentary rocks. They usually dip monoclinally to the south, deviating from that direction only in fault zones and about volcanic necks.

The northern neck is located in a wide belt of andesitic lavas, tuffaceous lavas, and tuffs of the same composition. North of the neck, the section contain tuffaceous sandstone and shale. The lava flows are usually rather thin (4 to 5 m) and are interbedded with tuffaceous units 15 to 25 m thick. As many as 4 or 5 flows separated by tuffs are present in individual exposures on slopes of low erosional ridges.

Petrographically, lava flows enclosing the neck are represented by plagioandesite — dark-gray fine-grained rocks with coarse inclusions of feldspar.

As seen under a microscope, the hyalopilitic to intersertal groundmass consists of microlites of plagioclase, brown glass, and chlorite segments. Comparatively coarse (1 to 3 mm) phenocrysts are represented by epidotic and sussuritic andesine. The phenocrysts show definite evidence of kinetic metamorphism as reflected in their wavy (mosaic) extinction and cataclastic cracks.

Plagioandesite tuffs display, both macro- and microscopically, extraordinary similarity with their effusive correlatives, so that they can be differentiated only in the field. Because of their low resistance to weathering, in contrast to the resistant lava flows, tuffs are represented in outcrops by friable brownish-gray rocks commonly fragmented by a hammer blow. On the slopes of the sopkas, away from the direction of dip, lava flows are exposed in crests reminiscent of dikes while outcrops of tuffs are marked by hollows. A multiple

FIGURE 3. "Bomb" horizon in andesite tuff, Katu Mountains.

alternation of such crests and hollows on some slopes resembles the so-called "cuesta landscape."

Volcanic bombs are lapilli, round to elongated bodies ranging in size from an egg to a watermelon or larger (Figure 3), are present in considerable amounts in tuffaceous beds. The bombs are scattered in the tuff bed; being more resistant than the latter, they are usually outlined by weathering and easily knocked out by a geologic hammer.

Volcanic bombs are marked by intensive epidotization considerably exceeding that in tuffs and developed chiefly in joint planes. Not uncommon are bombs transformed to a monomineral epidote rock. Such selective metasomatism, chiefly affecting coarse clastic material, is most probably related to the development of joints, with coarser and harder fragments, bombs and lapilli, at their intersections. Thus bombs turned up in one of these joint "nodes" with hydrothermal solutions flowing through it in all directions.

Under the microscope, tuff is almost indistinguishable from common plagioandesite. The texture of its groundmass is very reminiscent of hyalopilitic or intersertal textures with crystals and crystal fragments of plagioclase (andesine) reminiscent of phenocrysts of extrusive varieties.

The great petrographic similarity between these extrusives and their pyroclastic equivalents is a typical feature of rocks from that petrographic province and should be taken into consideration in field and office study.

The contact of the northern neck rocks and enclosing rocks is not everywhere sharp. The contact line between light extrusive rocks and dark plagioandesite interbedded with tuff runs parallel to the slope. The actual contact may lie not far from the base of the sopka, but has not been observed with certainty (nor have apophyses, xenoliths, or contact metamorphism) anywhere in natural exposures.

Elements of the occurrence of extrusive sequences are not distinct in the immediate vicinity of the neck. Nevertheless, it looks as though lava flows about the neck were somewhat uplifted in a dome-like bulge with the neck at the center.

Felsite dikes. A number of felsite and plagiorhyolite dikes have been observed along the periphery of the northern neck. In composition, they are similar to the crater facies described above. Some of the dikes are a considerable distance away from the neck but their connection with the crater is emphasized by their orientation: they are associated with radial faults or joints which controlled the formation of the neck itself.

One of the larger dikes, about 4 km long and 2 to 10 m wide, trends N35° E, southeast of the neck. It is well expressed in relief as a low ridge trending at an angle to the strike of the volcanic rocks. To the southeast, it is offset along a sublatitudinal fault. For one kilometer along that fault, at the dike contact and away from it, there is a zone of intensive

mineralization represented by epidote rocks with verdigris and copper sulfides.

2. Central Neck

The central neck is located 3.5 km south-southwest of the northern one, in a deep hollow surrounded by an amphitheater of mountains (Figure 4). It is an oval elongated to the northeast in plan. Felsites which form it are highly quartzitic, light gray to buff, against the brick red of unaltered rocks. A columnar parting developed on its slopes emphasizes its vertical flow structure.

Morphologically, the central neck appears to consist of two parts. The main body is elongated, having been formed apparently in the central vent; the narrower northern tongue is associated with a northeasterly trending fault (Figure 5).

The main body, separated from the northern tongue by a deep and narrow canyon, stands 120 to 150 m above the surrounding valley. Its diameter at the base is 300 to 350 m, with a base area of about 600,000 m^2. A chaotic pile-up of cliffs, with three peaks standing en echelon in their midst make up the neck. Jutting southeast of the main body is an apophysis about 150 m long and separated from it by a deep gorge; jutting to the northwest is a narrow rocky crest, about 300 m long and 100 to 120 m wide, with two sharp peaks.

Petrographic description of rocks. Rocks of the central neck are felsite and an hydrothermal alteration product, sericitic-alunitic-kaolinitic secondary quartzite. Macroscopically, these are light-colored, pink to commonly cream-white, dense cryptocrystalline granular rocks, from massive types to those displaying a definite flow structure.

As seen under a microscope, the felsite consists of a homogeneous, semi-crystalline quartzose feldspathic groundmass. Commonly developed in it are fine-scale aggregates of kaolinite less commonly with sericite, alunite, and granular bodies of secondary quartz. Phenocrysts of plagioclase and other minerals formed in an intratellurian crystallization stage are rare; accordingly, these rocks can be termed felsite rather than felsite porphyry or plagiorhyolite as are the northern neck rocks.

The most common products of hydrothermal alteration of felsite within this neck belong to a low temperature alunite-kaolinite facies of secondary quartzite. Under the microscope these rocks are seen to consist of fine-scale kaolinite aggregates and subordinate accumulations and isolated scales of sericite, alunite, and grains of hydrothermal quartz. Relict segments of a cryptocrystalline quartzose feldspathic felsite mass are occasionally present.

The more altered, quartzitic varieties most commonly occur in the peripheral part of the neck, especially in apophyses and dikes.

Flow structure in the central neck rocks is by far not as distinct and uniform as it is in the northern neck. It is noticeable only in weathered surfaces of massive varieties of felsite where it shows up in a peculiar vertical columnar parting.

However, detailed observations confirm the presence of steep (60 to 70°) dips in the flow structure toward the center of the neck, and a strike parallel to its walls.

The magnitude of the flow structure dip provides some criterion for the depth of erosion. It may be assumed that steeper dips, approaching the vertical, will be observed for a deeper erosional cut, while a shallow erosion, affecting only the top of an extrusion, will probably uncover flatter dips in the flow structure, oriented toward the center of the eruptive vent.

If the flow structure is not always distinct in felsite, the vertical columnar parting is very conspicuous, everywhere. Observed at the neck slopes from top to base are a series of long and narrow polyhedrons broken up into blocks by horizontal fractures. Characteristically, the polyhedrons are not strictly vertical but tilted in various directions, according to the direction of flow of a rising viscous magmatic melt.

The enclosing rocks and their relationship with the neck rocks. On its south side, the neck is fringed by a narrow (30 to 50 m) band of tuffaceous agglomerate, breccia, and tuff of an andesite-dacite composition changing upward to purple tuffaceous lavas and tuffs which form a thick unit.

Pyroclastic rocks around the neck form a definite domal structure dipping in all directions away from it. The origin of such a structure, as convincingly shown by R. W. Van Bemmelen, was due to the pressure of magma rising to the surface because "of the volume of its flow exceeded the capacity of a volcanic vent..." ([1], p. 57).

Alternating beds of tuff, tuffaceous breccia, and agglomerate are really inconsistent, commonly replacing one another. Individual layers exhibit a fair stratification.

A study of the relationship between the enclosing rocks and the central neck, carried out at a number of natural exposures, convincingly demonstrates the fluid nature of the contact. This is very graphically shown at the east side of the neck (exposures 684 and 875). Here,

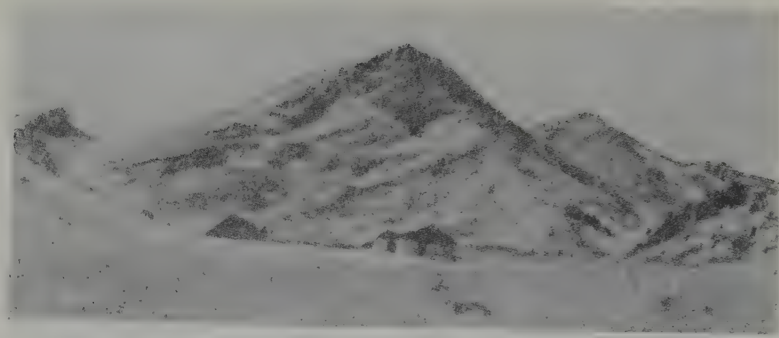

FIGURE 4. Central neck, Katu Mountains, View from the north.

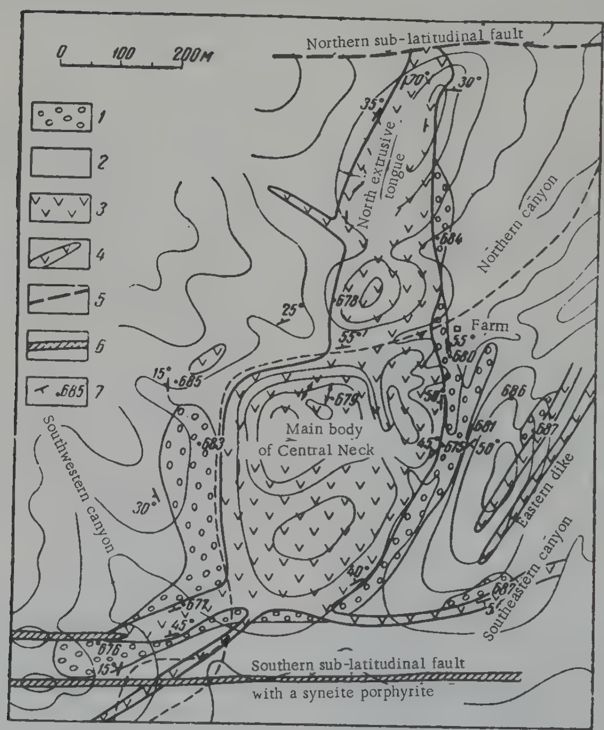

FIGURE 5. Central felsitic neck, Katu Mountains, and its vicinity (structure and morphology).

1) tuffs, tuffaceous agglomerate and breccia of andesite-dacite; 2) tuff and tuffaceous lava of andesite-dacite; 3) extrusive felsite of the neck; 4) felsite dikes; 5) fault traces; 6) sublatitudinal faults with syenite-porphyry dikes; 7) elements of occurrence of extrusive porphyrite, flow structure in felsite, and outcrop numbers.

felsite exhibiting an excellent, nearly vertical flow structure forms a cliff whose sheer side, facing east, is in contact with tuffaceous agglomerate at its base. The almost vertical contact surface is very distinct over a distance of several meters, trending submeridionally. The felsite face shows protuberances and inclusions of pyroclastic rocks, probably poorly preserved fragments of small xenoliths. Tuffaceous breccias at the contact are appreciably baked and locally lighter colored.

The data at hand are inadequate as yet for a solution of the problem of the relationship between pyroclastic and neck rocks and of their age in relation to a definite eruptive stage (which has produced a volcanic structure whose remains are described here as the central neck). Considering the general geologic situation of this region, and particularly the wide development of similar pyroclastics in areas free of the volcanic center remains, it is most probable that pyroclastics surrounding the central neck had originated prior to the eruption responsible for the central felsitic neck. As such, they constituted only a passive medium.

On the other hand, their definite association with the necks, as well as the development of similar tuffaceous agglomerate and breccia around some other volcanic centers, as we have noted in our description of the Arkharla Mountain [4], suggests a relationship between pyroclastics and an eruption preceding the formation of these volcanic centers. In that event, the central neck may be an example of the more complex volcanic structure preserved since the Permian.

Felsite and plagiosyenite porphyry dikes. A large felsite dike is located southeast of the central neck. It extends for over 400 m east-southeast and is 3 to 5 m thick. It appears to be an apophysis out of the neck. West of the neck, there are three shorter (200 to 300 m) and thinner dikes trending east-northeast. Northeast trending dikes are also present east of the neck. Very characteristic are the apophytic dikes south of the neck; one of them, trending northeast, is definitely cut by a sublatitudinal syenite-porphyry dike.

Dikes of plagiosyenite-porphyry occur south and east of the central neck. They are oriented sublatitudinally, are fairly wide (5 to 10 m) and up to several hundred meters long, cutting the

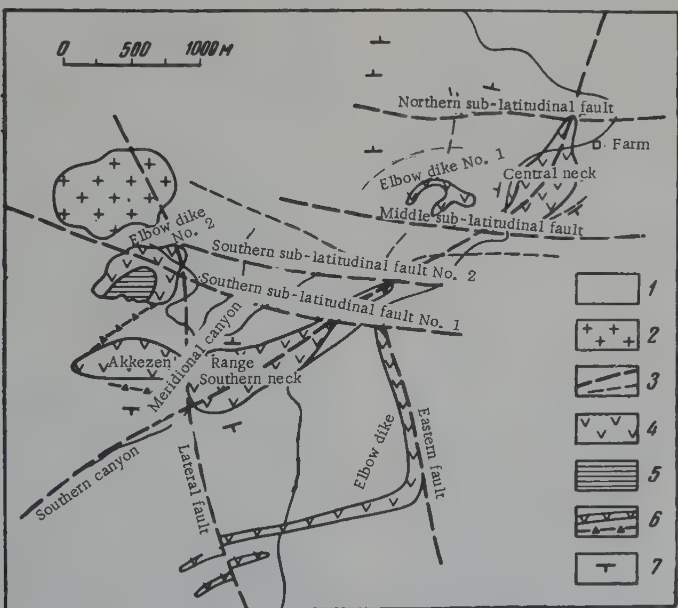

FIGURE 6. Structural geologic diagram of the central and southern necks, Katu Mountains.

1) Permian extrusives of andesite-dacite composition; 2) late Variscan granodiorite and granosyenite; 3) fault traces; 4) Permian extrusive felsite necks and apophysis dikes; 5) secondary quartzite; 6) dikes of felsite and porphyrite; 7) elements of occurrence of extrusive porphyrite.

felsite dikes and the felsite neck, as shown in Figure 6. The hydrothermally altered pyroclastic rocks, in their eastern contact with the central neck, show a copper mineralization in blotches of verdigris.

3. Necks and Felsite Dikes of the Southern Group

One kilometer south of the central neck there is a series of intrusive bodies, closely related to one another areally. Unlike the above-mentioned comparatively simple volcanic centers, the southern group of extrusive bodies is considerably more complex. That has been brought about to a considerable extent by the tectonic effect of several faults crossing one another. Components of this group are the southern neck or the Ak-Kezen' Ridge; an annular felsite dike; and the southeastern "elbow dike." In addition there are widely developed felsite dikes, as though they were joining together the larger bodies, and sublatitudinal-trending syenite-porphyry dikes.

Morphology of the extrusive bodies. The southern neck (Ak-Kezen' Ridge) is an elongated sickle-like body concave to the north and extending sublatitudinally for 1750 m; its maximum width in the middle is 350 to 400 m, and is 30 to 50 m at the ends. A deep meridional canyon cuts it in two: a larger eastern segment and a smaller western one. The eastern segment, trending northeast, is formed by two parallel crests separated by a narrow gorge. The northwestern crest, not as broken up as the other, extends far to the east from the meridional canyon, thus participating in the structure of the entire ridge. The southeastern crest, more dissected, is short and wedges out 250 to 300 m away from the meridional canyon. The western part of the ridge is formed by a single crest trending sublatitudinally. This crest gets narrower, to the west, from 200 to 50 m and gradually disappears.

An annular felsite dike is located 500 m north of the southern neck. It consists of a chain of peaks in an amphitheatre enclosing an interior hollow. This chain of peaks is broken only in the south where there is a passage up to 200 m wide (a quadrant of the circumference). The interior hollow is formed by small peaks (sopkas) of hydrothermally altered quartzitic and epidotic pyroclastic rocks mineralized by sulfides and carbonates of copper. The outside diameter of the dike is about 500 m; the inside, about 300 m; the dike itself is 60 to 100 m wide. The hollow area within the dike is about 75,000 m^2. The symmetric annular shape of the ring is somewhat distorted in the northeast where its width is abruptly increased by a short but wide apophysis shooting out in that direction. The apophysis is separated from the dike by a deep cut and stands out in relief like an independent peak.

A southeastern elbow dike is located southeast of the Ak-Kezen' Ridge and is made up of quartzitic felsite almost completely altered to alunitic-kaolinitic secondary quartzite. It starts at the northeastern end of the Ak-Kezen' Ridge and extends south for 1.5 km along an eastern fault, then veers sharply, almost at a right angle, to the west and continues west-southwest for an additional 1700 m. Its over-all length is, then, more than 3 km. Its thickness varies from 50 m in the middle to 10 m at the ends. Running parallel to its western slope is an apophysis, up to 400 m long and 5 to 10 m wide. Lateral shifts on northwesterly faults trending toward the meridional canyon are present on the same side. The elbow dike is represented by a low ridge of cream-white to ocher kaolinitic rocks.

Petrographic description of the neck and dike rocks. The southern neck, as well as the dikes, is formed by hydrothermally altered felsite, turned mostly to secondary alunitic-kaolinitic quartzite.

The slightly altered varieties of these rocks are pink and are massive or have a flow structure. Under the microscope, their cryptocrystalline quartzose feldspar groundmass shows a well-expressed spherulitic texture. Inclusions are missing, as a rule. Only in some localities (specimen 1500, top of Ak-Kezen') are there fairly coarse phenocrysts of sossuritic plagioclase (andesine) and fused quartz grains. As a rule, the groundmass in even slightly altered varieties has fine-scale aggregates and isolated tabular crystals of kaolinite as well as columnar aggregates of hydrothermal quartz.

In strongly altered varieties, kaolinite and in places alunite completely replace the original groundmass and the rock is changed to a cream-white alunitic-kaolinitic secondary quartzite.

Flow structure and parting. Flow structure in felsite of the south group is not distinct; in a number of places it takes a close look to discover it. It looks as though its presence is determined by and revealed in not only the composition and the cooling conditions of a magma (its viscosity, rate of cooling, the presence of volatiles, etc.) but by hydrothermal metamorphism which has completely camouflaged, in many places, the primary structural and textural features of felsite. Nevertheless, a fairly definite, almost vertical flow structure has been observed in a number of exposures, especially in the segments of less altered rocks of the southern neck and the annular dike, with traces of eddying in some exposures in the south slopes of the neck.

Vertical columnar parting in felsite of the southern group is widely developed in rocky slopes of the southern neck where it is not

different from that described for the northern and central necks.

The enclosing rocks around the extrusive felsite are represented by tuffaceous breccia and coarse, clastic andesite-dacite tuff. Tuffaceous breccia and tuff form alternating beds, very consistent laterally. Because of this, a cursory look may mistake them for normal sediments, as witness the name "tuffaceous rocks," under which they are often known.

Over a distance of 60 m on the south side of the Ak-Kezen' Ridge, transverse to the strike, there are ten south-dipping layers of tuffaceous breccia and coarse-grained tuff, each one 4 to 8 m thick. Up to the same number of similar beds, dipping north, were counted from the base to the top of one of the sopkas, over a distance of 50 m across the strike on the north side of the ridge.

Macroscopically, tuff and tuffaceous breccia are brown-gray to greenish-gray dense, fine- to medium-grained rocks. Their color is due chiefly to epidotization and carbonatization, especially intensive in individual beds. The granularity of rocks is more intensive in some beds than in others.

A microscopic study of the less altered varieties of pyroclastic rocks makes it possible to differentiate three types, of tuffaceous breccia and coarse-grained tuff, depending on the nature of their cement:

1. Those consisting of angular fragments of andesite lavas and tuffs, cemented with fine-grained tuff of the same andesite composition. Such rocks carry a large amount of sickle- to saber-shaped ash particles of non-crystallized and chloritized volcanic glass, very typical of pyroclastics.

2. Those represented by angular to poorly-rounded fragments of andesite lava with a pellicular-type cement of semi-crystallized vitreous material.

3. Those consisting of andesite lava fragments of a fine hyalopilitic texture immersed in a cementing groundmass which accounts for up to 50% of the total rock. The cement is an andesitic tuff consisting of a brown vitreous groundmass with fragments of feldspar crystals.

These varieties of tuffaceous breccia and coarse-grained tuff are characterized by an extremely homogeneous petrographic composition: they are represented by andesite-dacite lavas alone, without other sedimentary and igneous rocks. This homogeneous composition is the best evidence of their pyroclastic rather than normal sedimentary nature.

A study of the conditions of occurrence of these rocks shows that they form a clean-cut domal structure, somewhat elongated in conformity with the shape of the southern neck. South of the latter, pyroclastic beds near their contact with felsite are dipping south at 55 to 60°, gradually flattening away from the contact; north of the neck, the beds show a gentler dip (30 to 35°) in northerly directions and also gradually flatten to the north. In both occurrences, the strike is sublatitudinal, parallel to the neck walls.

Dikes of plagiosyenite porphyry, widely distributed in the southern neck area, are younger formations which cut the extrusive and dike felsite bodies north of the neck. One of such dikes extends for over 2 km west-northwest. On the east side, where it cuts the southern neck felsite, the dike is represented by a small ridge up to 50 m wide. It is thinner to the northwest where it is not over 2 m wide within the annular felsite dike. Farther west, this dike and the fault controlling it pass by the south contact of the granodiorite stock. The second plagiosyenite-porphyry dike runs parallel to the first, 250 to 300 m to the north and is traceable for over 2 km, with a width of 20 to 50 m.

Macroscopically, plagiosyenite porphyry is a dense rock consisting of a pink to flesh-red K-feldspar groundmass with coarse phenocrysts of white plagioclase and a bottle-green amphibole. Under the microscope the groundmass exhibits a definite spherulitic texture reminiccent of the texture of felsite described above. Present in it almost always are isolated aggregates of a brown pelitic K-feldspathic substance. Plagioclase phenocrysts are represented by coarse tablets of sussuritic andesine. Fairly coarse amphibole phenocrysts are almost fully replaced by chlorite.

Dikes of diorite porphyry are not as well developed here. One of them has been observed south of the Ak-Kezen' Ridge, among pyroclastic rocks. It extends for several jundred meter, latitudinally, conformable to the strike of the enclosing rocks and it is about one meter wide. The age relationship of dikes and the neck felsite is not clear, except that the dikes probably are the youngest rocks. The dike rock is greenish-black and has a fine-grained groundmass with phenocrysts of plagioclase and hornblende standing out against it. There are probably more such diorite-porphyry dikes in the southern neck area but they are difficult to map.

SOME GENERALIZATIONS AND CONCLUSIONS

Hydrothermal Processes and Ore Mineralization

Extremely common in the neck rocks and in

the enclosing pyroclastics were post-igneous processes which altered the extrusive felsites and, to a lesser extent, their enclosing rocks to low-temperature alunitic-kaolinitic varieties of secondary quartzite and also resulted in widespread epidotization and carbonatization of the enclosing rocks.

Such selective metasomatism, i. e., the formation of secondary quartzite in some instances and epidote rocks in some others, is explained by the mineral and chemical composition of the rocks themselves: the more acid, essentially K-felsite and the more basic, essentially Ca pyroclastics. In addition, the path of movement of those solutions which were most active within the necks, chiefly along their periphery and their contacts with the enclosing rocks was of some importance.

The hydrothermal activity was expressed not only in the above-named processes of silicification, epidotization, alunitization, and kaolinitization but also in the deposition of copper sulfides which occur in hydrothermally altered rocks in the periphery of all three necks as well as within the annular dike.

Copper mineralization on the periphery of the northern neck is present along a sublatitudinal zone marked by a band of epidote rocks with a dispersion of verdigris and secondary copper sulfides (including covellite). This mineralization zone is located at its intersection with a northeasterly trending regional fault which controls the disposition of all three volcanic centers. The zone extends for over one kilometer on either side of the fault. Its thickness is not known precisely but is not less than 5 or 10 m.

Copper mineralization is best developed in thin hydrothermally altered pyroclastics near their eastern contact with the central neck. However, a general contamination with copper in malachite blotches is much more common.

In the area of the southern dike group and the southern neck, copper mineralization is most intensive in the annular dike hollow. Here, an area of 20,000 to 30,000 m^2 of visible copper mineralization of verdigris and secondary sulfides occures in intensively silicified and epidotized pyroclastics near their contact with felsite. Undoubtedly, this mineralization was brought about by the damming effect of the felsite dike; as such, may be a prospective copper-porphyry ore. Their presence in the annular dike suggests their wider distribution in the Katu Mountains; some of these ore showings may be commercial.

Structural Control

The areal distribution of volcanic necks and dikes as well as their morphologic features is controlled mostly by regional faults trending northeast, northwest, and places submeridionally, and by their associated faults of the second and third order.

The effect of a northeasterly-trending regional fault is revealed in the distribution of the volcanic necks; they all lie along the same structural line, from the southern neck at its southwestern end to the northern neck at its northeastern end. The distance between the southern and central necks does not exceed 1 km, with up to 5 km from the central to the northern neck. Related to the same structural line is the northern felsite dike which extends for over 4 km along this regional fault.

The morphologic features of the necks, above all of the southern and the central, have been fully determined by this northeasterly-trending structural line (the neck fault). The two necks, as seen in Figure 6, are elongated to the northeast.

Other felsite dikes, such as the southern one, are controlled by local faults and have a submeridional trend. This is the reason for the peculiar elbow-shaped trend of that dike.

A series of plagiosyenite-porphyry dikes developed about the central and southern dikes is related to northwesterly (sublatitudinal) faults. It is possible that these faults were not fully developed during the intrusion of felsitic magma. That came about later on, during the injection of the plagiosyenite-porphyry dikes and of diorite porphyry after them.

The second, extremely interesting ore- and magma-controlling factor are the annular structures such as the annular dike. Most probably, annular fractures were due to microdomal uplifts caused in turn by a flow of felsitic magma toward the surface. This may be an explanation for the association of annular dikes with areas of development of volcanic centers.

Illustrated in Figure 6 is a complex disjuntive structure studied in some detail in the area of the central and southern necks. The following features stand out here against a background of gentle sublatitudinal folds in Permian extrusives and pyroclastics:

1. A small stock of post-Variscan granodiorite, northwest of the southern neck. Being a satellite of a large granitoid intrusion south of the Katu Mountains, it cuts a Lower Permian extrusive sequence which conformably overlies Upper Carboniferous extrusives.

2. A northeast-trending regional tectonic zone of weakening, broken up by northeasterly-trending fractures. This zone controls a chain of Permian intrusions, their necks, and auxiliary dikes, all described in this paper. It may be supposed that this minor tectonic zone of weakening could have originated along the eastern edge of a buried foundation of the west Katu late Variscan granitoid intrusion, as the result of a "settling" of that body following its crystallization and cooling.

3. Connected with this regional northeasterly-trending zone and its fractures is the localization of felsite necks elongated from southwest to northeast.

4. Intruded together with the necks along the northeast- and north-northwest-trending faults were felsitic and annular dikes near the central and southern necks.

5. Later on, syenite-porphyry dikes, originating in the same magmatic hearth, were intruded along the sublatitudinal faults bordering the necks in the north and south or only in the north.

6. Finally, the rare but fairly long diorite-porphyry dikes were formed at the very close of the extrusive period.

Figure 6 (scale 1:25,000) graphically illustrates the complex disjunctive tectonics in one of northeastern zones of the Katu Mountains, not noticed by geologists in mapping at a scale of 1:200,000 and even 1:100,000. These tectonics, along with Permian extrusions, the necks and apophytic dikes, is typical of the entire southwestern part of the Dzhungari Alatau Range. It is present in the Arkharla and Chulak mountains [4], as well as in the Katu, and probably east of there.

The Relationship between Extrusive and Intrusive Rocks and the Evolution of Magma

A close spatial and genetic (comagmatic) connection determined by the existence of a common magma chamber is observed clearly in studying the relationships and the petrographic composition of the extrusive felsites and the plagiosyenite porphyry dikes.

In regard to their spatial disposition, the plagiosyenite dikes, as we have seen, tend to occur in areas in which felsite necks and dikes are developed, thus testifying to their emergence along the same magma channels, after a small interruption in time.

In their petrographic composition and chemistry the plagiosyenite porphyries, plagiorhyolites and felsites are very close to each other: the basic magma of all of them consisted of poorly differentiated, essentially felspathic matter, frequently with a spherulitic structure. The phenocrysts in the plagiosyenite porphyries and plagiorhyolites are represented by intermediate plagioclase, the difference lying only in their quantity — in the plagiosyenite porphyry they form up to 40% of the rock. In addition, the plagiosyenite porphyry contains numerous amphibole phenocrysts, which are lacking in the plagiorhyolites.

On the basis of these data, along with the conclusion of the existence of a common magma chamber, and thus of a close magmatic relationship, one may infer that the evolution of the magma's composition in the magma chamber during the Permian proceeded from a more acidic alkali-earth magma to a more basic magma of alkaline nature.

The geologic age of the extrusives of Mt. Katu has been determined as Early Permian, since they cut through Lower Permian extrusives and their pyroclastic derivatives, and the necks and their dike-apophyses are composed mainly of felsites that in all respects resemble the felsites of the extrusive necks of Mt. Arkharly and Mt. Chulak, which also intersect Lower Permian extrusive-pyroclastic formations.

The hydrothermal processes associated with the magma chambers of the felsitic extrusives, particularly the formation of the apoextrusive secondary quartzites, have followed exactly the same course in all three areas — Arkharly, Chulak and Katu. The hypogene mineralizations of the secondary quartzites in these areas, represented chiefly by copper and partly by gold and silver (Arkharly), are also very similar.

The paragenetic relationships between the ore mineralization and the Permian secondary quartzites and extrusive necks characterize certain metallogenic features of the southern slopes of the Dzhungar Alatau, and may serve as guides for the location of copper and gold in this region.

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LEACHING OF DISSOLVED ALUMINUM BY THERMAL WATERS OF THE KURILE RIDGE AND SOME PROBLEMS ON THE FORMATION OF GEOSYNCLINAL BAUXITE DEPOSITS [1]

by

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Acid thermal waters, formed in provinces of active volcanism, leach Al, Fe, and other elements out of rocks. Large amounts of dissolved aluminum are carried out to the sea where they are precipitated in suspension as hydrated aluminum oxide. One of the minor thermal streams carries a daily load of over 65 metric tons of dissolved aluminum and about 35 tons of iron in solution to the Sea of Okhotsk. This process may contribute to the understanding of the problem of aluminum sources for a number of geosynclinal deposits of bauxite.

* * * * *

Data presented in this paper was developed for part of a symposium on "Modern Volcanism and Its Effect on Marine Sedimentation," organized at the Geological Institute, AS U. S. S. R., for a clarification of the role of volcanic processes in the formation of volcanic sedimentary rocks, and deposits of sedimentary industrial minerals. This is the least known aspect of such sedimentary minerals at the present time, although even the most cursory observations reveal considerable redistribution of various elements in areas of active volcanism.

The author takes this opportunity to extend his deep gratitude and sincere appreciation to E. S. Zalmanzon, Director of the Chemical Laboratory at the Geological Institute, AS U. S. S. R., who has given much time and energy to the search for and introduction to the methods of analysis and calculation of complex natural acid waters and suspensions; to M. A. Kanakina and Ye. S. Shishova who carried out the analytic portion of this work; and to S. A. Brusilovskiy who suggested the conversion method for analyses of acid waters.

* * *

The end of a volcanic process is reflected in geologic sections usually by the disappearance of extrusive products, lavas and pyroclastic material. As a matter of fact, however, volcanic activity is far from being terminated with an ejection of solid material. The subsequent slow cooling of a liquid lava which has approached the surface through a volcanic vent is accompanied by the separation and rise of assorted gases, HCl, H_2S, H_2O, SO_2, $B(OH)_3$, CO_2, and others, all vented into the atmosphere. In other words, the comparatively brief process of a catastrophic eruption of lava and ashes gives place to a longer and more stable period of consecutive fumarole, solfatara, and mofette activity in a volcano, classified according to temperature and composition of gases emanating from a cooling magma. For recent eruptions, which are comparatively minor in the history of the earth, such cooling processes are expressed in a loss of heat into the atmosphere; these eruptive periods last for thousands and tens of thousands of years or longer [9].

Not all of the gases escape directly into the atmosphere; some of them dissolve in water vapor while some others dissolve in vadose waters circulating through rocks which form the volcanic structures. Acid fumarole waters result from this; their origin in the Kurile Islands and Kamchatka have been considered in detail by V. V. Ivanov [15, 17]. It has been determined that the rate of flow for condensation waters is usually very low (hundredths, rarely tenths of a liter per second) while that for thermal springs formed by ground, artesian, or surface waters is measured in several liters and tens of liters per second.

It is only natural that such waters which are, roughly speaking, a mixture of various acids (their pH is 0 to 3) react together with volcanic gases on rocks through which they circulate [19]. As a result, the waters are enriched in

[1] Vynos rastvorennogo alyuminiya termal'nymi vodami Kuril'skoy Gryady i nekotoryye voprosy obrazovaniya geosinklinal'nykh mestorozhdeniy boksitov.

alkalies, alkaline earths, iron, and aluminum, which go into solution almost completely, in the course of acid dissociation of extrusive rocks.

The interaction of acid thermal waters with various enclosing rocks is well illustrated in the area of Ebeko volcano, now in a solfatara stage.

Ebeko volcano is located in the northern part of Paramushir Island and is formed chiefly by bedded andesite and andesite-basalt lavas and tuffs. The top of the central cone (1138 m) has three adjoining craters, 200 to 300 m in diameter each, aligned meridionally. A hot acid lake forms in the central crater. The cone and its immediate vicinity are covered by much pyroclastic material formed during the 1935 eruption. The western sector of the central cone is fringed by young flows of andesite lava with a lumpy surface [12, 13, 16].

The present activity of Ebeko is manifested in numerous large solfataras distributed in its craters and along its slopes. Ravines in the slopes have exposed a large number of thermal springs, differing in temperature, composition, and output. Earlier solfatara activity of the volcano is suggested by the large area of ancient lavas bleached by hydrothermal solutions (Figure 1).

The largest solfataras are in the south crater where there is a powerful boiling spring ejecting gases and water spray up to 2 m high; there is also a group of roaring solfataras and a small boiling spring, Belyy Spring (White Spring), on the northeastern slope. Many solfataras are located along the shores of Goryacheye (Hot) Lake, in the central crater, and at the bottom of the lake where spots of surging "boiling" water have been observed.

Waters of most thermal springs exposed by ravines in the volcano slopes are gathered into three individual drainage channels. The eastern slope springs, uncovered in the upper part of the cone and draining pyroclastics of the 1935 eruption, join Kuz'minka River which belongs to the Pacific basin. The western slope springs (of the Sea of Okhotsk basin) give rise to two thermal streams, the Gorshkova and Yur'yeva. The Gorshkova, whose valley received the main flow of young andesite block lavas of a recent eruption, collects thermal waters cheifly from the area of these lavas. Springs giving rise to the most abundant Yur'yeva thermal stream flow out of fractures in older lava and tuffaceous lava sheets [14].

Analyses of the cation composition of each of these streams have led to amazing conclusions. It turned out that in the springs of the Gorshkova headwaters alkaline and alkaline-earth cations predominate over all others carried out of the young lava sheet; they account for over 50% of the total. Waters from springs in the upper course of the Kuz'minka draining fresh pyroclastic material, contain a large amount of alkaline-earth cations and a higher than average amount of alkaline cations. Aluminum and iron cations predominate in thermal waters of the Yur'yeva basin which drain the same older lava flow, with alkaline earths and alkalies being subordinate (Table 1). All this points fairly definitely to a close connection between acid waters and the enclosing rock from which various metals are leached by thermal waters.

There is another evidence of water-carrying rocks being the source of metals dissolved in these waters. The fact is that condensed thermal waters which pass through the middle of a large field of bleached and decomposed rocks, as they do in the central funnel of the southern crater, carry few metal cations, despite their high acidity (pH = 0.08) and high potential capacity for reaction. At the same time, condensation waters emerging at the edge of a zone of decomposed rocks (e. g., Belyy spring) show a decidedly higher aluminum content. Quite obviously this is due to the fact that Belyy spring condensate has passed through less decomposed rocks.

The intensity of leaching of metals from extrusive rocks by hydrothermal waters can be judged from the composition of decomposed and bleached rocks which now are mostly a siliceous skeleton preserving the structure of former extrusives. Table 2 presents the results of an analysis of samples from the same lava flow, from the watershed (a) and from the channel of an acid thermal stream (b). It is obvious that only silica and some titanium are left in the bleached rock. Where in the undecomposed lava $TiO_2/SiO_2 = 0.022$, it is 0.011 in its bleached fraction, i. e., the titanium content is half as high as the silica. Moreover, inasmuch as residual silica is only a fraction of the original, the amount of leached titanium should be assumed to be even larger. Thus even such a stable element as titanium is leached by thermal waters as a result of acid dissociation. At the same time, no titanium has been detected in most acid waters. This is explained by the fact that hydrated titanium oxide coagulates at about pH 1 and is transported not in solution but most likely in the finest suspension. Unfortunately, it is rather difficult to detect this suspension in the littoral part of the Kuriles because it appears to be camouflaged in a precipitate by the large quantity of terrigenous titanium minerals.

Acid dissociation of extrusive rocks by volcanic gases and thermal waters, with leaching of the bulk of metals, is fairly common in volcanic provinces. The interior of volcanoes passing or having passed the hydrothermal-solfatara stage is almost completely given over

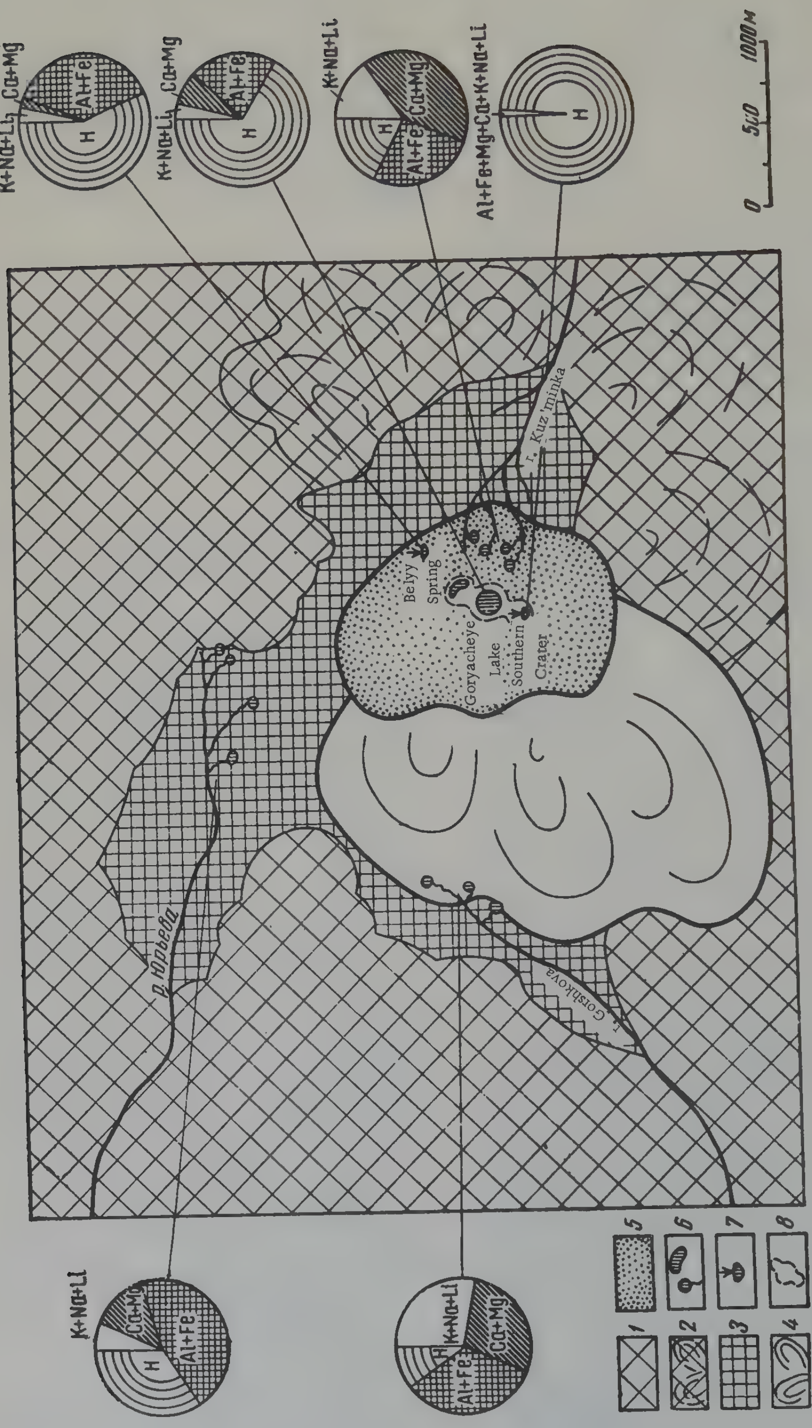

FIGURE 1. Diagram of the cation composition in waters of Ebeko volcano

1) undecomposed basic lava and tuff; 2) old flows of andesite lava with a lumpy surface; 3) zone of bleached rocks; 4) young flows of andesite lava with a lumpy surface; 5) pyroclastic material of the 1935 eruption; 6) acid springs and lakes; 7) solfataras with condensation waters; 8) Ebeko craters.

Table 1

Composition of Ebeko Volcano Waters[1] (M. A. Kanakina, analyst)

Components	Mouth of upper crater		Belyy spring		Goryacheye Lake		Verkhn-yeur'yevskiy spring		Mouth of Yur'yeva R.		Headwaters of Gorshkova R.		Headwaters of Kuz'minka R.	
	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %	mg/liter	mg-equiv. %
$H^{\cdot}$	1279.4	99.01	531.0	56.64	60.40	67.79	141.37	38.50	28.96	25.54	3.64	10.76	4.78	15.10
$Al^{\cdot\cdot\cdot}$	39.52	0.34	2950.7	35.00	132.90	16.59	1200.42	36.33	435.36	42.67	79.23	26.02	53.00	18.61
$Ti^{\cdot\cdot\cdot\cdot}$	5.52	0.04	Traces	—	None	—	None	—	None	—	None	—	None	—
$Fe^{\cdot\cdot\cdot}$	23.68	0.10	42.10	0.24	28.75	1.73	13.60	0.20	205.56	9.71	36.55	6.00	43.69	7.39
$FeOH^{\cdot\cdot}$					2.55	0.04			9.49	0.24			24.82	2.15
$Fe^{\cdot\cdot}$	26.59	0.07	517.10	1.98	58.50	2.34	660.02	6.42	None	—	None	—	None	—
$Ce^{\cdot\cdot}$	25.01	0.09	235.8	1.26	105.4	5.90	543.0	7.39	117.5	7.76	115.0	17.00	178.6	28.15
$Mg^{\cdot\cdot}$	15.29	0.10	72.08	0.63	22.94	2.12	241.3	5.41	86.0	6.23	47.5	11.56	55.70	14.47
$K^{\cdot}$	8.46	0.02	423.3	1.16	4.23	0.12	220.0	1.54	77.5	1.75	None	—	None	—
$Na^{\cdot}$	64.91	0.22	645.2	2.99	62.95	3.08	328.0	3.88	151.25	5.79	206.5	26.55	90.49	12.42
$Li^{\cdot}$	1.26	0.01	7.57	0.10	1.89	0.30	8.50	0.33	2.50	0.31	5.0	2.11	3.79	1.71
Total		100.00		100.00		100.00		100.00		100.00		100.00		100.00
Cl'	45156.0	98.59	27019.0	81.27	2086.8	66.04	4673.88	35.85	1431.95	35.59	Not determ.	Not determ.	206.8	18.42
HSO_4'	658.63	0.52	9535.10	10.48	1334.7	15.44	6943.26	19.50	1382.25	12.57	"	"	188.18	6.13
SO_4''	79.68	0.13	4439.04	9.86	796.8	18.63	6549.12	37.16	2937.60	53.99	"	"	1087.2	71.56
F'	1—2	—	3—4	—	None	—	Not determ.		Not determ.		"	"	None	—
Br'	3.00	—	None	—	"	—	"		"		"	"	0.70	—
J'	1.00	—	"	—	"	—	"		"		"	"	None	—
Total		99.24		101.61		100.11		92.51		102.15				96.11
Dry residue	1528.0		28326.0		3356.0		20784.0		7052.0		1652.0		2112.0	
SiO_2	221.0		160.0		184.0		274.0		144.0		86.0		225.0	
B_2O_5	3.6		1.17		9.8		Not determ.		Not determ.		Not determ.		1.17	
pH	0.08		0.435		1.30		1.12		1.72		2.38		2.38	
Acidity	1279.4		Not determ.		Not determ.		141.37		28.96		Not determ.		Not determ.	

[1] This table is computed in milligrams per liter of water. The method of computation for analyses of acid waters will be described in detail in a forthcoming paper. For convenience in subsequent conclusions, the amount of cations is taken as 100%; accordingly, the percentage of error of the analysis, multiplied by two, is assigned to anions.

Table 2

Hydrothermal Alteration in Ebeko Lavas (Ye. S. Shishova, analyst)

Spec. No.	Rock	% air - dry sample														
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	H_2O^+	H_2O^-	CO_2	Total
a	Unaltered Ebeko lava	52.59	1.15	21.22	4.00	3.94	0.10	7.20	3.40	2.70	1.90	0.27	0.42	1.42	0.57	100.79
b	Same in the channel of a thermal spring	93.69	1.11	1.43	0.02	0.21	Traces	0.40	0.05	0.03	0.05	None	None	0.30	0.06	100.26

Table 3

Composition of Limonite Suspension in Thermal Waters of Iturup and Kunashir Islands (Ye. S. Shishova, analyst)

Spec. No.	Island	Drainage channel	% dry sample																		
			SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	S	Cl	H_2O^+	CO_2	C	Σ	O=S	$Σ_2$	H_2O^-
240	Iturup	Lake Tikhoye	1.61	0.06	1.29	56.73	10.75	0.27	0.23	1.48	0.23	1.33	7.78	None	0.01	16.89	0.85	0.06	99.58	—	—	71.51
1316	"	Limonite Cascade	0.36	Traces	0.55	72.92	4.06	0.13	0.14	0.09	0.15	0.93	5.14	"	None	13.29	0.19	1.50	99.48	—	—	24.82
208	Kunashir	Kislyy Creek	8.53	0.36	3.02	61.56	2.82	0.19	0.05	0.11	0.15	0.25	8.12	1.15	Traces	14.13	0.14	0.70	101.28	0.51	100.71	52.97
204	"	Lesnaya R.	1.87	0.33	0.62	70.62	1.49	0.11	0.03	0.08	0.13	0.32	8.20	0.30	"	13.87	0.43	1.80	100.20	0.15	100.05	64.33

Table 4

Composition of Material in Suspension in the Sea of Okhotsk Waters Near the Mouths of Yur'yeva and Severnyy Chirip Rivers (M. A. Kanakina and Ye. S. Shishova, analysts)

Sample Nos.	Location of sample	% dry sample																Without sea water salts		
		SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	SO_3	Cl	CO_2	H_2O^+	$Σ_1$	O−Cl	$Σ_2$	SiO_2	Al_2O_3	Fe_2O_3
1	near mouth of Yur'yeva R.	2.01	18.90	None	4.81	2.87	1.18	2.97	18.48	0.61	6.88	24.39	0.43	16.19	99.72	5.50	94.22	7.82	73.48	18.70
2	" "	1.23	36.18	"	1.15	1.83												3.05	89.58	7.37
3	" "	None	20.05	"	4.98							25.54						None	80.10	19.90
4	near mouth of Severnyy Chirip R.	4.42	9.82	"	52.43	1.32												6.50	14.44	79.06
5	" "	None	24.17	"	31.61													None	43.33	56.67
6	" "	"	32.40	"	17.18													"	65.35	34.65

to zones of bleached rocks uncovered to depths of tens and hundred of meters. It is with these zones that numerous deposits of volcanic sulfur are associated in extinct and active volcanoes of the Kuriles and Japan [6, 7]. A vast zone of hydrothermally decomposed rocks occurs in the province east of the present Sredinnyy (Middle) Range divide on Kamchatka, designated by G. M. Vlasov as the "Neogene zone of secondary quartzite" [8]. According to him, this majestic belt of thick kaolinitic, sericitic, alunitic, diaspore, sulfur-bearing, and other secondary quartzites made up an arcuate chain of volcanic islands during a considerable part of the Tertiary.

Ancient zones of acid dissociation in extrusive rocks do not occur merely in isolated localities. Rather they are fairly large areas of altered rocks. This is brought about first by the wide distribution of vadose waters activated by the solution of volcanic gases; second, by migration of the volcanic zone itself, i. e., by a successive shifting of volcanoes and craters along faults. In explaining this phenomenon which promotes the preservation of sulfur deposits (and the accompanying bleached rocks), so startling at first glance, G. M. Vlasov states, "There are many volcanic and crater chains where the oldest volcano shows no signs of activity, the next younger is in the fumarole stage, the third is at the height of its volcanic force, the fourth, usually a slag cone, is just beginning to develop as a volcano, etc. This phenomenon appears to be related to plugging up of volcanic vents by eruption products which force lavas and gases to seek new outlets along the fissure." ([8], p. 169).

As a result of the wide circulation of activated acid thermal waters through extrusive rocks, they are enriched in a number of elements such as aluminum, iron, silica, alkaline earths, and alkalies. The aluminum content in solution reaches 2 to 3 gm/liter; iron, 0. 5 to 1 gm/liter, in the ferrous state. When water-bearing beds are uncovered by erosion, they give rise to a series of abundant thermal springs whose waters, upon entering a common drainage channel, commingle with other meteoric waters. In this process, ferrous iron changes to ferric and the hydrogen-ion concentration decreases.

This lowering of the hydrogen-ion concentration is the decisive factor in the subsequent precipitation of elements out of solution. It is well known that individual compounds, such as hydrates of oxides, are precipitated at a specific pH. Thus, $Fe(OH)_3$ begins to fall out at about pH 2; $Al(OH)_3$ at pH = 4. 1; $Cu(OH)_2$ at pH = 5. 4; $Fe(OH)_2$ at pH = 5. 5; $Pb(OH)_2$ at pH = 6; $Ni(OH)_2$ at pH = 6. 7; $Co(OH)_2$ at pH = 6. 8; $Mn(OH)_2$ at pH = 8. 5 to 8. 8; $Mg(OH)_2$ at pH = 10. 5, etc. [21].

These data show that ferrous iron remains in solution up to pH = 5. 5 while ferric iron precipitates at pH = 2–3. For that reason, the issuance of thermal waters with pH greater than 2 is accompanied by an intensive precipitation of iron changing from the ferrous to the ferric state. Inasmuch as this takes place as soon as thermal waters issue at the surface, a precipitation of ferric oxid hydrate is observed in all springs with pH greater than 2. This is especially well demonstrated in the crater of the Bogdan Khmel'nitskiy volcano (Iturup Island).

The crater of this volcano has a vast funnel, over 1. 5 km in diameter and up to 500 m deep, located in decomposed rocks bleached white, between Chirip and Bogdan Khmel'nitskiy peaks and formerly filled up by a large crater lake. At the present time, the west wall of the crater is cut by the deep gorge of Severnyy Chirip River and only the sediments are left from the crater lake. Several small basins, the largest of which, Lake Tikhoye, has a diameter of about 300 m and is up to 8 m deep are located in the northern part of the crater. These basins, lined up in a chain and connected by a stream flowing into the Severnyy Chirip, is a site of intensive limonite deposition (Figure 2).

Iron and aluminum are brought in to Lake Tikhoye chiefly by a cold acid spring at its northeastern end, flowing about 60 liters/sec of water with a pH of about 3. One liter of its water contains 75 mg aluminum and 188 mg ferrous iron. The iron, upon oxidation as it reaches the surface, precipitates at the bottom of the lakes and their connecting stream, forming an area about 0. 5 km^2 of a peculiar limonite deposit which we have named Limonite Cascades.

The present thickness of limonite in individual places at the Limonite Cascade is 10 to 12 m. The limonite so deposited has cemented the traces of recent human activity: hewn stakes, bottles, etc. The intensive deposition of limonite causes migration of the stream, as a result of which the area of limonite distribution grows ever larger. Locally there are peculiar limonite "wells" and "knobs" with small ponds at their tops, formed by minor springs. Limonite is deposited by the overflowing water; as a result, a "knob" or "well" rises ever higher, becomes isolated from the stream, and in places a considerable height.

Each liter of water flowing into the Severnyy Chirip yields about 3 mg ferric iron. Thus, some 185 x 60 x 86400 mg iron, or a little less than one metric ton a day, goes into suspension in lakes of the Limonite Cascade. Some of this suspension undoubtedly is carried out into the Sea of Okhotsk.

The exceptional purity of this lake limonite should be noted (Table 3). By far most spectrographic analyses reveal only insignificant additions of Mn, V, and Ni. The bulk of aluminum

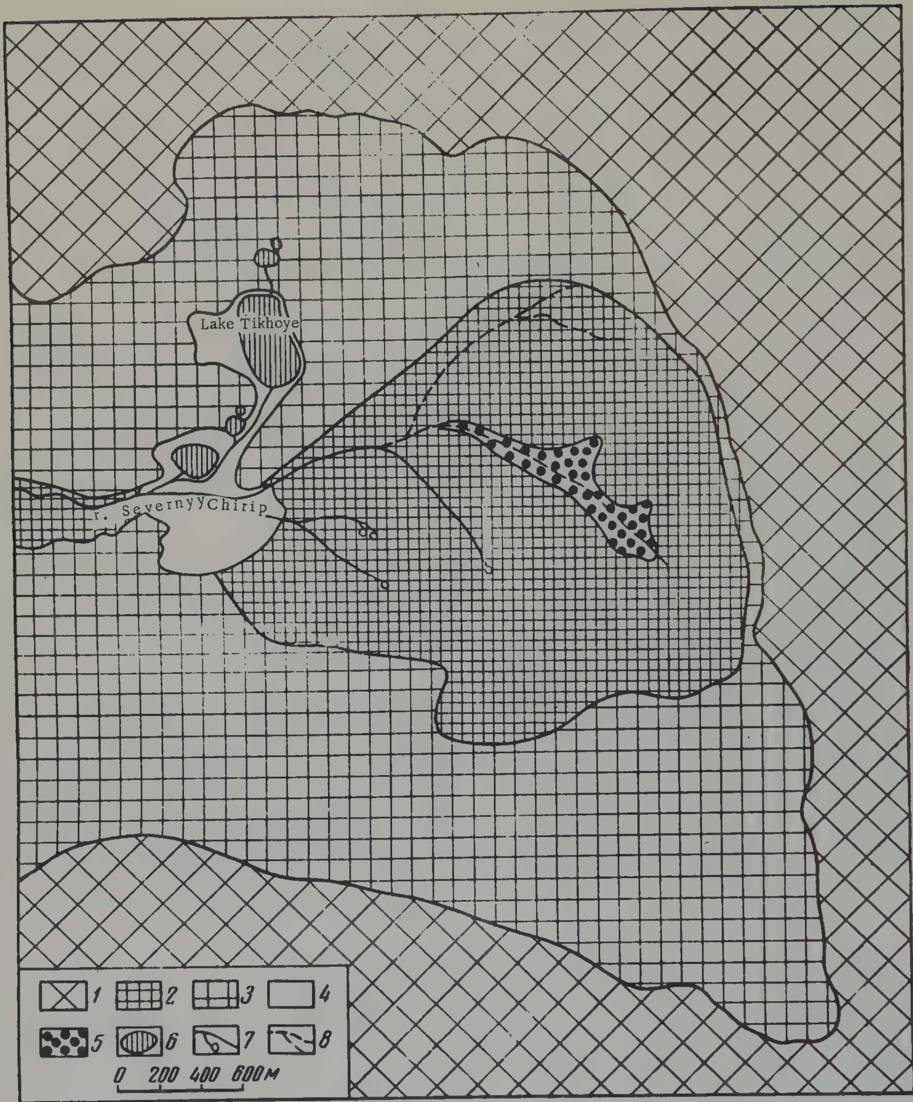

FIGURE 2. Diagram of the Limonite Cascade iron ore deposit (Iturup Island)

1) undecomposed basic lava and tuff; 2) zone of decomposed (kaolinitized and opalized) lava and tuff; 3) slightly decomposed lava and tuff; 4) present accumulations of limonite; 5) limonite cementing fragments of bleached zone rocks; 6) lakes of acid water where limonite is deposited; 7) springs and streams of acid water; 8) fresh-water springs.

remains in solution and goes into suspension only out in the sea where it forms, together with the mechanically carried limonite suspension, a rich yellow train of cloudy water.

Precipitation of limonite out of thermal springs or out of waters commingling with them can be observed to various extents on all islands with thermal springs. On Kunashir Island, for example, a limonite suspension with about 70% Fe_2O_3 is deposited in large amounts at the mouth of Lesnaya River which gathers thermal waters of Mendeleyev volcano. Here, as in other places, the limonite is very pure, with hardly any additives. Aluminum, which is usually twice as abundant as iron in feeder springs remains in solution.

The rise in pH of water in flow channels where upwelling ground water commingles with

meteroic water, proceeds very slowly. The fact is that, on the basis of pH being a negative logarithm of the hydrogen-ion concentration, the amount of meteoric water necessary to reduce the latter by each unit of pH increases in a geometric progression, with a denominator of 10. Thus, a rise in pH of thermal waters up to 4.1, i.e. to the point of precipitation of hydrated aluminum oxide, requires a better than thousandfold dilution of the original volume of thermal waters by meteoric waters.

In the Kuriles, however, aluminum remains in solution even when pH of the commingled waters attains 5 and better.

This apparent contradiction is explained as follows: Even the early experiments of H. T. S. Britton [3] demonstrated that only aluminum sulfate coagulates at pH = 4.1, while aluminum chloride remains in solution. H. T. S. Britton states, "In the reaction of aluminum chloride with oxides of strontium and barium, the solution remained clear until 2.09 equiv. alkalie (pH = 4.76) was added, in the first instance, and 1.92 equiv. alkali (pH = 4.69) in the second. After that, the solutions became opalescent, with coagulation occurring only at the addition of 2.71 and 2.88 equiv. alkalie, respectively, and as pH attained a considerably higher value of 6.5. This lag in precipitation, despite the fact that the prerequisite value of pH = 4.14 was exceeded with nearly the entire stoichiometric amount of alkalie added, is explained by a characteristic tendency of chlorides to form colloidal solutions, with dispersion particles formed at the initial stage too small to change the aspect of the solution for the naked eye." ([3], p. 294). Inasmuch as hydrochloric acid is one of the main reagents in thermal waters of the Kuriles, the aluminum chlorides so formed persist in solution, causing that peculiar light-blue opalescent nue to waters of many Kurile rivers.

It is important to keep in mind that waters of the Kurile hydrographic system, commingled with thermal waters, never attain the pH value of 6.5. This because of two main reasons. First, a simple calculation shows that the total atmospheric precipitation, about 1 m per year [23], is quite inadequate for the required five million-fold dilution of thermal waters; second, the meteoric waters themselves, having dissolved gaseous products of volcanic activity while on their way down through the air, reach the earth with a somewhat higher concentration of hydrogen-ions [1, 22]. Suffice it to say that

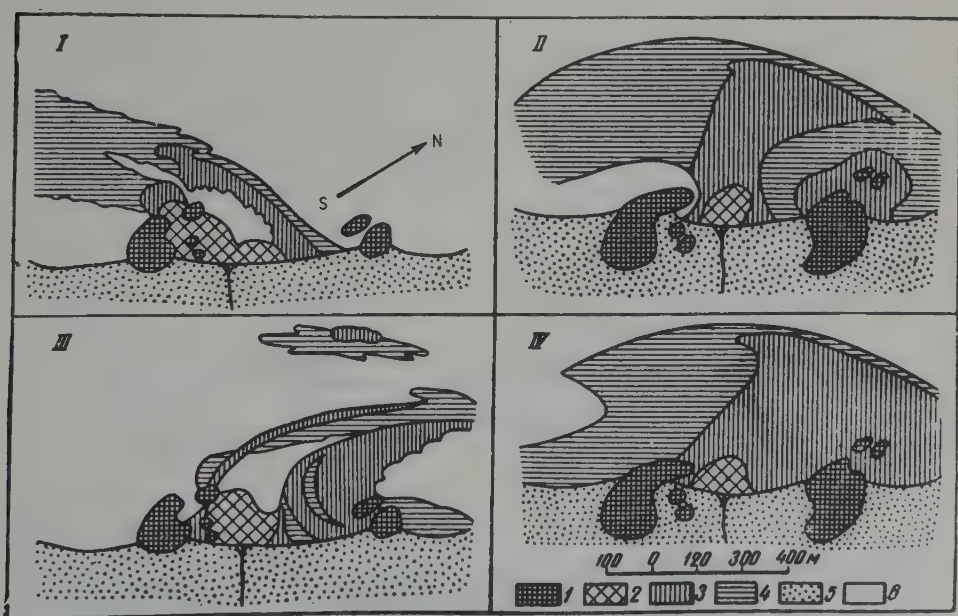

FIGURE 3. Perspective sketches of $Al(OH)_3$ + Fe_2O_3 suspension trains in the Sea of Okhotsk, at the mouth of Yur'yeva River, September 1957.

I - tide immediately after a high storm wind; II - low tide, waves 3 to 4 points, strong surf; III - high tide, calm, strong south current; IV - low tide, calm; 1 - coastal cliffs; 2 - zone of deep green transparent water (beginning of the commingling of Yur'yeva River and marine water); 3 - zone of intensive precipitation of $Al(OH)_3$ + Fe_2O_3 suspension; 4 - zone of semitransparent blue-green water; 5 - beach gravel; 6 - sea water.

Table 5

Composition of Ooze in the Littoral Zone of the Sea of Okhotsk near the Mouth of Yur'yeva River
(M. A. Kanakina and Ye. S. Shishova, analysts)

Sample Nos.	% of dry sample											
	SiO_2			TiO_2	Al_2O_3		Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O
	determined	including in 10 % NaOH	including quartz		determined	including in 10 % NaOH						
508	20.94	13.22	0.21	0.69	20.73	20.71	12.07	2.72	Traces	1.35	1.38	5.22
501	35.76	17.24	0.15	0.57	20.05	15.75	1.54	5.98	0.04	3.80	2.33	5.21
505	43.19	17.24	2.04	0.67	18.09	10.95	5.61	3.80	0.05	4.10	2.58	4.57

well water in the town of Yuzhno-Kuril'sk, exclusively meteoric and not contaminated with any thermal waters, has a pH of 5. 5.

For that reason, aluminum which gets into solution as a chloride, in the process of hydrothermal volcanic activity, always remains there until carried out to the Sea of Okhotsk or the Pacific.

The reaction between thermal and marine water is best demonstrated by the Yur'yeva River which flows into the Sea of Okhotsk at a rate of 1. 8 m^3/sec, has a pH = 1. 72, and carries at its mouth 205 mg of ferric iron and 435 mg aluminum per liter.

of yellow turbidity is formed out in the sea. It has a blue-green fringe and is clearly divisible into three parts. The first, with a radius of 50 to 80 m from the mouth, is represented by deep-green transparent water and is the zone of initial commingling. The next and larger zone (up to 1. 5 km) is the site of intensive fall-out of yellow flakes of oxide hydrates. Particles suspended in the upper layer of water form noticeable "billows" and "clouds" of turbidity with a very sharp boundary at the edge of the zone. Spreading farther out for several kilometers is a blue-green semi-transparent zone free of yellow suspension flakes (Figure 3). The average dimensions of the train, persisting through all storms, is 3000 x 300 x 2 = 1. 8

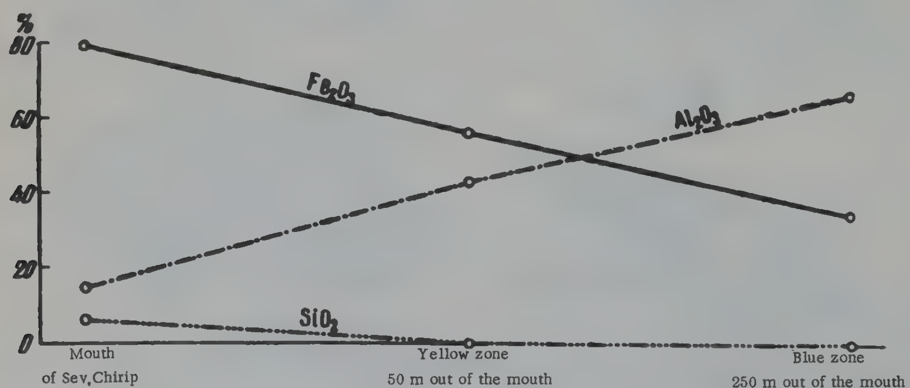

FIGURE 4. Relationship between SiO_2, Al_2O_3, and Fe_2O_3 in suspensions formed by Severnyy Chirip River in the Sea of Okhotsk.

In the commingling of acid thermal waters and alkaline marine water, a conspicuous train

million m^3. This corresponds to a volume of sea water necessary to reduce the Yur'yeva

Table 5 Continued

% of dry sample												
K_2O	P_2O_5	S	SO_3	Cl	CO_2	C	H_2O^+	Σ_1	O–S	$O-Cl_2$	Σ_2	H_2O^-
0.75	1.80	0.57	5.82	6.56	0.13	5.31	15.86	101.90	0.28	1.48	100.14	78.36
1.14	0.87	1.72	1.80	5.02	0.56	4.57	11.43	102.39	1.13	1.13	100.40	78.99
1.43	0.81	0.72	1.42	5.31	0.10	3.44	7.02	102.91	1.20	1.20	101.35	70.76

waters, each second (1.8×10^6 = 1.8 million m^3). Judging from the analyses of water from the Yur'yeva mouth, about 35 tons of iron and over 65 tons aluminum are precipitated daily in that train.

An analysis of the suspension taken at sea has shown a 18.9 to 36.1% Al_2O_3 content with 3 to 8% Fe_2O_3 and up to 2% SiO_2 (Table 4). Inasmuch as this marine suspension was dried but not washed prior to the analysis, a considerable number of samples turned out to consist largely of salts (e.g., sodium, calcium, and magnesium chlorides) precipitated out of sea water in drying. This is confirmed by the conversion made by E. S. Zalmanzon for sample 1, with the following salt composition of the sample analysed, (in % of dry sample):

NaCl	— 34.85
KCl	— 0.96
$MgCl_2$	— 3.77
$MgSO_4$	— 4.12
$CaSO_4$	— 1.53
$CaCO_3$	— 0.98
$FeSO_4$	— 6.06
	52.27

All these salts, except for iron sulfate, indeed are components of sea water where they occur in about the same amounts as bear the Yur'yeva mouth. The presence of iron sulfate is explained by the fact that ferrous oxide (2.87% FeO) can exist only in this form, in a sample which has been stored for some time. After a computation of the salt composition, there was an excess of 0.05% SO_3, which is the analytic error.

The second half of sample 1 consisted of the following:

SiO_2	— 2.01
Al_2O_3	— 18.90
Fe_2O_3	— 4.86
H_2O^+	— 16.19
	41.91

The remaining fraction of the sample (about 6%) was organic matter, apparently plankton and algae unevenly distributed in suspension. A determination of C_{org} in this sample, from different batches, has given different figures, all less than 6%.

It is of interest that SiO_2 was detected only in samples from the uppermost film of sea water (Table 4), and that only in samples nearest to the shore and in very small amounts (up to 4.4%). This can only mean that SiO_2 here is a mechanical terrigenous addition. The true suspension, precipitated as a result of commingling of acid and marine waters consists out in the sea chiefly of Al_2O_3, Fe_2O_3, and H_2O^+, i.e., both aluminum and the groundmass are present as hydroxides. This makes it possible to assume the $SiO_2 + Al_2O_3 + Fe_2O_3$ to be 100% and to regard as equivalent to sample 1 all analyses of other samples collected under similar conditions and which yielded, because of their very low content of inorganic material, only silica and hydroxides.

A conversion to a salt-free composition, done on this basis, shows that the Al_2O_3 content in the Yur'yeva water suspension reaches 89%.

It is interesting to compare a series of weighed samples from different zones at the Severnyy Chirip mouth (Table 4, samples 4-6). Salt-free samples right at the mouth contain 14% Al_2O_3; the Al_2O_3 content rises to 43% in the yellow zone, and to 65% in the blue. The iron content grows correspondingly lower; from

80% near the shore to 35% in the blue zone; SiO_2, obviously of a terrigenous orgin, has been noted only at the very mouth, in the amount of 6.5% (Figure 4). It is clear that hydrated aluminum oxide is precipitated in the farthest reaches of the train.

Under the present hydrodynamic conditions in the Sea of Okhotsk, hydrated aluminum oxide is spread over the entire basin. We succeeded in collecting some ooze in the zone of tide wash among the rocks. It contained a settled suspension of $Al_2O_3 + Fe_2O_3$ mixed with SiO_2 and TiO_2, which probably was brought in with the finest clastic material from disintegrating bleached zones (Table 5). As shown in a 10% NaOH extract, by far the largest quantity of Al_2O_3 in these samples was represented by free alumina.

Yur'yeva and Severnyy Chirip Rivers are not an exception in the Kurile ridge islands. According to geographic data [18, 23], rivers forming a similar suspension out in the sea flow from solfatara fields of volcanoes "Machekha" and "Kudryavyy" on Iturup Island, and Ivao volcano on Urup Island. They have also been noted in the crater of the submerged Ushishir volcano, on Shishkotan, Ketoy, Broutona, Makanrushi, and "Chernyye Brat'ya" islands and in many other places. The total amount of aluminum carried in solution from the Kurile ridge islands can be safely estimated at thousands of tons per day.

It is noteworthy that all these data have a direct bearing on the problem of origin of geosynclinal bauxite deposits.

The theory of a chemical origin of bauxite, propounded over 20 years ago by A. D. Arkhangel'skiy [2], has been developed and found valid to a considerable extent in a number of bauxite deposits [4, 10, 11]. At the same time, A. D. Arkhangel'skiy and his followers have not offered a sufficiently convincing explanation for the source of aluminum carried in solution in a marine basin. For that reason, his theory remained in serious doubt until recently [5]. Attempts of A. V. Peyve, N. A. Shtreys, and A. L. Yanshin to explain the origin of bauxite from alumina of volcanic thermal solutions [20] received no support.

It is natural to assume that bauxite could have originated as a result of various geochemical processes involving a redistribution of aluminum and that an understanding of each particular process calls for a long and painstaking study. The speculations of many students of bauxite have been directed, in one way or another, toward the process of weather; in that respect, the study has been far advanced. Our own geologists, in possession of extensive material on the geology of geosynclinal deposits, did not have the chance, until recently, to get acquainted in detail with volcanic processes on island arcs. Such an opportunity has presented itself very recently.

The data set forth above allow us to regard acid thermal waters of volcanic provinces as a major source of aluminum in sea basins, sufficient for the formation of bauxite deposits. A consideration of postvolcanic processes emphasizes the abundance of dissolved alumina, assiduously carried out to sea by thermal waters, and in the most mobile form, that of a chloride, at that. Considering that a specific volume of thermal water requires almost a million-fold volume of sea water in order to precipitate hydrated aluminum oxide from the chloride, it is readily seen that the upper sea layer could have been contaminated over considerable areas by hydrated aluminum oxide gradually going into suspension as a result of the intensive hydrothermal activity of the past. The bulk of suspended hydrate, upon settling at the bottom, was undoubtedly made leaner by terrigenous and pyroclastic material. At the same time, conditions favorable for accumulation of comparatively abundant and pure suspensions could have been present locally, leading to its subsequent change to bauxite. It is quite probable that thermal solutions following sufficiently intensive volcanic processes of the past were somewhat more acid, with a pH less than 1; precisely such solutions prevail in condensation waters of the present. In that event, the appearance of titanium and assorted rare elements in bauxite is quite legitimate because low pH values in thermal waters are optimum for migration conditions which were believed to be unrealizable under natural conditions [5]. It is possible, however, that titanium could have been added to bauxite as a fine mechanical impurity, as in oozes of the Okhotsk littoral zone.

What were the burial conditions for such a large amount of incoming free alumina? Without getting into details of specific known deposits, we shall attempt to clear up those features which are not clearly explained by other means. It appears that the fairly common association of bauxite with underlying carbonate bioherm deposits is not accidental. First of all, such facies were developed in clear water free of terrigenous material; secondly, they modified sharply the pH of the medium and promoted an intensive precipitation of oxide hydrates. In that connection, a Karst aspect of the carbonate floor under the bauxite becomes understandable; most likely this floor was undermined by acid marine water. The sedimentary volcanic nature of bauxite also would explain the fact that bauxite of geosynclinal deposits usually wedges out without any correlative elements in other facies. This is due to an

intensive, but geologically brief, stage of post-volcanic solfatara activity. Also deciphered is the relationship of bauxite to the interval immediately following a period of intensive extrusive activity, i.e., the beginning of active hydrothermal processes. Seen in this light, the arbitrary and often fruitless search for a weathered crust and the disintegration products in provinces of the development of bauxite deposits becomes understandable.

Without regarding all these data as proof of a sedimentary volcanic origin of bauxite, I want to suggest that bauxite geologists review the field data extant by considering the possibility that the processes of leaching alumina in the Kuriles may be a key to the origin of some geosynclinal bauxite deposits.

In addition, the presence of such processes raises the prospect of finding new bauxite deposits of the sedimentary volcanic type and of forecasting the areas of their development. Generally speaking, these should be areas where the close of volcanic activity (a definite stage of geosynclinal development) coincided with a wide development of carbonate, chiefly bioherm, facies.

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GEOTHERMAL ZONATION OF WEST SIBERIAN ARTESIAN BASIN[1]

by

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We understand the term "geothermal zone" to mean a rock interval where rocks and their ground water are characterized by a definite temperature interval.

There is, as yet, no single criterion in scientific literature for the selection of such intervals. In the International Balneologic Classification by temperature, all springs are divided into 1) cold, below 20°C; 2) sub-thermal, from 20 to 37°C; thermal, 37 to 42°; and hypothermal, above 42°. In this classification, the boundary between sub-thermal and thermal waters is the temperature of the human body.

In one of the latest works on geothermy, F. A. Makarenko and V. V. Ivanov [6] differentiate two main geothermal belts within upper levels of the crust: 1) belts with seasonal temperature changes, including their negative values, in regions of frost and permafrost; 2) belts with stable thermal conditions. In the latter, hydrothermal zones are differentiated by the following water temperatures: 1) below 0°C; 2) 0 to 4°C; 3) 4 to 20°C; 4) 20 to 40°C; 5) 40 to 70°C; 6) 70 to 100°C; 7) above 100°C; and 8) above 374°. The authors regard these boundaries between zones as arbitrary. The two geothermal belts differ sharply in thickness. The first usually is not over 10 to 40 m thick in platform provinces (down to the neutral layer boundary); the thickness of the second belt is measured in many kilometers.

Where there are enough measurements for both belts, a separate analysis of geothermal conditions can be made for either one. However, as a rule in regional studies of large artesian basins, the data at hand do not allow such differentiation. In such cases, it is expedient to differentiate geothermal zones independently of the belts. In designating temperature intervals of geothermal zones, the following should be taken into account: 1) phase changes of water; 2) effect of temperature on the course of biochemical processes and the speed of chemical reactions; and 3) the feasibility of using ground water from a zone for practical purposes (water supply, balneology, beating, power generation, etc.).

The first factor is related to the change of water from liquid to the solid or gaseous state; in this process the critical points may not coincide with those for fresh water under atmospheric pressure (0°C and 100°C). Nevertheless, temperatures of 0° and 100°C can be accepted as critical; water with temperatures below 0°C is supercolled; water above 100°C, superheated.

The second factor greatly affects the hydrochemical zonation of ground water and is potent in the formation of oil and gas deposits. A critical temperature point for biochemical processes is about 50°C where the coagulation of proteins and the cessation of organic life take place. Chemical reactions, proceed most intensively, under artesian conditions, at temperatures from 20°-25° to 50-75°.

In the west Siberian artesian basin the main biochemical transformations, such as the exchange and precipitation of slightly soluble salts of calcium and magnesium, occurs at temperatures not over 50°C. As a result of such processes, ground water formerly with a diversified chemical composition (calcium hydrocarbonate, Na-Ca-sulfate-hydrocarbonate, sodium hydrocarbonate, and Na-chloride-hydrocarbonate) becomes of the same type, Ca-Na-chloride (chlore-calcium).

Because of the practical importance of ground water, it is expedient to differentiate five temperature zones: 1) not over 25°C, chiefly for water supply; 2) 25 to 50° for balneology, heating of green houses and hot beds; 3) 50 to 75° balneology, heating of agricultural buildings, small settlements, and spas; 4) 75 to 100°C, balneology and heating of large cities; 5) 100°C and up, for power generation.

On these considerations, we deem it expedient to differentiate geothermal (geotemperature) zones with intervals of 25°C.

[1] Geotermicheskaya zonal'nost' Zapadno-Sibirskogo artezianskogo basseyna.

Before turning to the description of geothermal conditions in the west Siberian artesian basin, we shall review its geologic structure, hydrogeologic conditions, and climatic features, inasmuch as temperature conditions depend mostly on these factors.

This basin is filled with Mesozoic and Cenozoic areno-argillaceous deposits, from hundreds of meters to 3 or 4 km thick. They rest on an uneven surface of a hard pre-Jurassic basement of sedimentary and metamorphic rocks cut in many places by intrusions. Porous Mesozoic and Cenozoic deposits have a number of aquifers with water moving slowly from the southeast and south, from main watersheds, to the north and northwest, to outlet areas.

Because of the low air temperatures prevailing in the northern part of the basin (mean annual temperatures range from -3.5°C to -10°C) and the length of the frost period, permafrost is widely developed here, with its southern boundary passing from Berezovo on the Ob to Yartzevo settlement on the Yenisey. Thickness of the frozen rocks reaches 300 m at Salekhard and increases to 450 m in the lower reaches of the Yenisey.

The undistrubed structure of the basin and its comparatively simple hydrogeologic conditions (the absence of known major discharge points, an extremely sluggish water exchange chiefly through relatively impermeable sequences) made it possible to obtain a fairly clear picture of the geothermal zonation of the basin from limited field data (temperature measurements in approximately 180 boreholes).

On the basis of these temperature measurements throughout the basin[2] we have designated six geothermal zones in the Mesozoic-Cenozoic beds, with the following temperatures: 1) below 0°C, supercooled water in both the liquid and the solid phase; 2) 0 to 25°C, essentially cold waters; 3) 25 to 50°C, sub-thermal waters; 4) 50 to 75°C, thermal waters; 5) 75 to 100°, highly thermal waters; and 6) over 100°C, superheated waters.

The zone boundaries are not drawn with the same precision everywhere. In a number of areas, especially in the west, northwest, and east, they are approximate; in central areas with more numerous measurements, they have been drawn with more certainty.

The lowest temperature of the basin has been determined for the Ust'-Port area where it is -5.2°C at a depth of 20 to 25 m. The highest temperature was measured in the Kolpashevo borehole, where it is about 125°C at a depth of approximately 2900 m. It should be noted that all geothermal zones with the exception of the deepest sixth are not associated with definite stratigraphic units but cut them. This is quite understandable considering that the thickness of individual formations varies sharply as does the depth of their occurrence. The relationship between geothermal (geotemperature) zones in the section is shown in Figures 1, 2, and 3.

The first geothermal zone is developed in the permafrost province and occupies the northern part of the basin. Its southern boundary coincides with the above-mentioned southern boundary of permafrost and its thickness ranges from a few meters in the south to 300 to 450 m in the north. Of all geothermal zones, this one has the most complicated temperature setup. In the belt of seasonal changes its annual temperature ranges from 1 to 5°C (in the summer) to -12°C (in the winter). Below a neutral layer (approximately below 20 m), the temperature gradually changes with depth, from -5° to 0°C (at the base of the zone). Present below river valleys and large lakes are bands and spots of thawed ground whose thickness reaches 180 m (beneath major river valleys). In addition, warmer waters seep from lower, mostly from the second, zones into the first one, to form thawed areas. As a result, the constitution of the lower boundary of this zone is complex.

The lower boundary lies in Tertiary deposits; in the north, it takes in some of the Cretaceous beds, down to the Aptian-Albian.

Within this zone, ground water is found mostly in the solid state. Only in its lower part can it exist in a supercooled liquid state, because of its higher mineralization (up to 15 gm[l. in the Ust'-Port area).

Because of low temperatures, biochemical processes are very weak, with chemical reactions between rocks and water and between waters of different mineralization, very sluggish.

The second geothermal zone is distributed over the entire artesian basin. Its thickness reaches 700 m, decreasing to 300 or 400 m in the northwest (Sos'va near-Ural region). This decrease in thickness is caused by the heat brought up by ground water from deeper parts of the basin to the drainage area and to a buried water outlet. A thinning of this zone has also been observed in the area of deep lake troughs near the northeastern boundary of the Kazakh highlands (Lake Ul'kun-Karoy and Lake Kzyl-Kak), where we recognized earlier the buried center of a partial outlet of ground water from deeper reaches of the basin [4]. The lower boundary of this zone passes through Lower

[2] Temperature was measured in deep boreholes of the Siberian Geophysical Trust, Novosibirsk and Tyumen Geological Administrations (former Zapsibneftegeologiya and Tyumen'neftegeologiya), Minusinneftegeologiya, and other organizations.

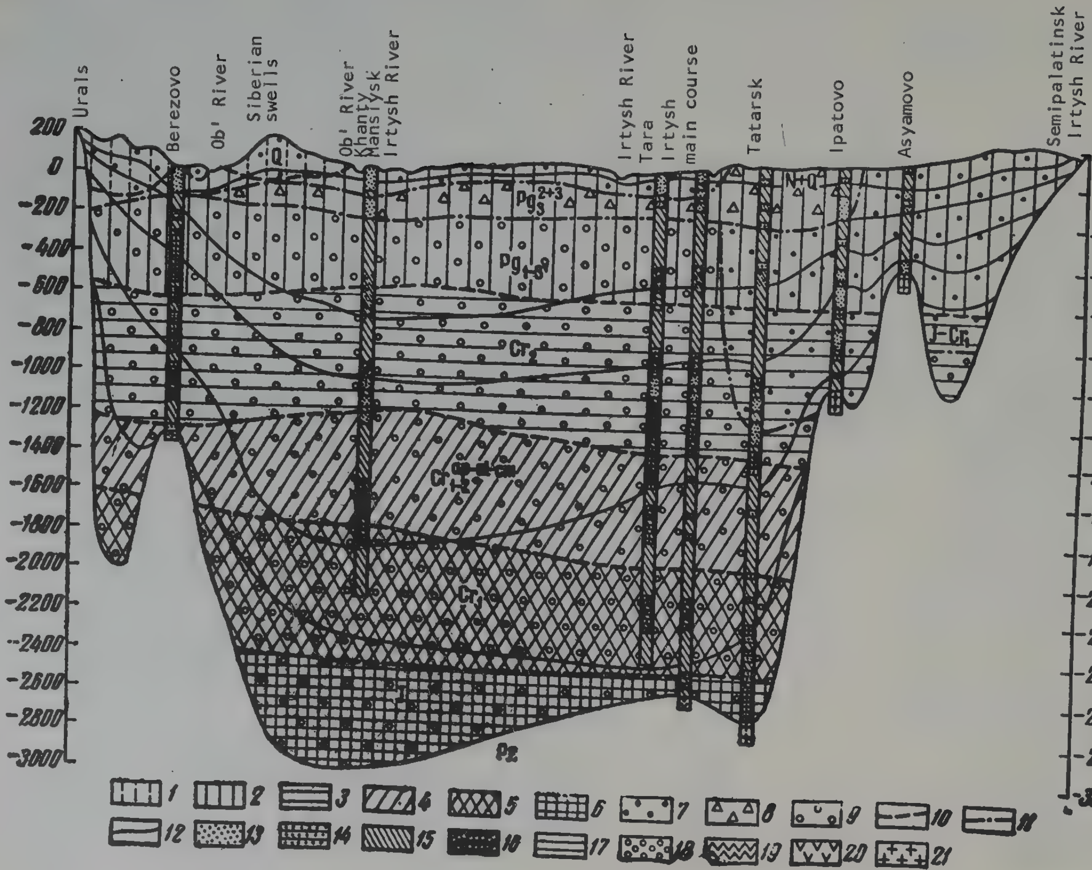

FIGURE 1. Geotemperature gradient along Berezovo-Bol'sherech'ye-Semipalatinsk section; by B.F. Mavritskiy, 1958.

Temperature zones; 1 - below 0°C; 2 - 0 to 25°C; 3 - 25 to 50°C; 4 - 50 to 75°C; 5 - 75 to 100°C; 6 - above 100°C. Hydrogeochemical zones: 7 - fresh and comparatively fresh water (mineralization, 0.5 to 3 gm/l), chiefly of infiltrational origin, sulfate-calcium-sodium, hydrocarbonate, nitrogen; 8 - braekish to salt water (mineralization, 3-10 gm/l), chiefly infiltrational sodium chloride-sulfate, nitrogen; 9 - waters from braekish to saline (mineralization, 3 to 35 gm/l) of a complex origin (mixture of connate and infiltrated waters), sodium chloride to calcium-sodium chloride methane and nitrogen-methane; 10 - boundaries of geotemperature zones; 11 - boundaries of hydrogeochemical zones; 12 - stratigraphic boundaries; 13 - sand and silt; 14 - sandstone and siltstone; 15 - clay and shale; 16 - siliceous claystone; 17 - marl; 18 - gravel and conglomerate; 19 - shale and metashale; 20 - tuff and tuffite; 21 - granite, granodiorite, syenite.

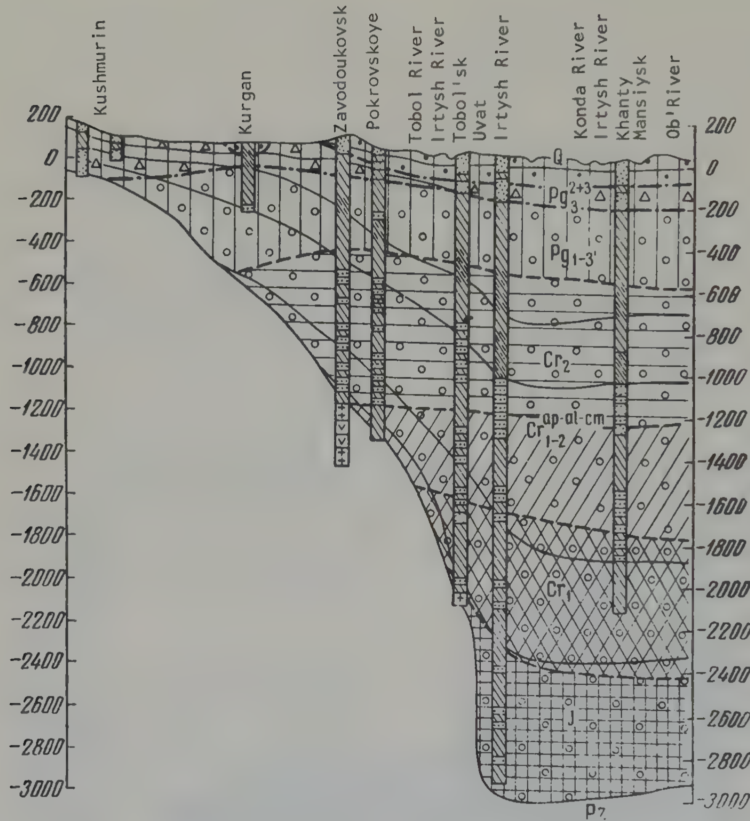

FIGURE 2. Geotemperature gradient along line Kushmurun - Pokrovskoye - Khanty Mansiysk section. Symbols the same as in Figure 1.

Tertiary and Cretaceous rocks, descending into Jurassic water-bearing deposits in the southeast, east, and northeast. This zone takes in the entire complex of water-saturated Oligocene continental rocks with temperatures ranging from 0° to 10 or 15°C. In the peripheral parts of the basin, this zone includes Cretaceous and Jurassic aquifers Predominant water types of this zone are sulfate-hydrocarbonate-magnesium-calcium and chloride-sulfate-magnesium-sodium, with a 1 to 10 gm/l. mineralization. We believe that the origin of sulfates is due chiefly to oxidation of pyrite (dispersed everywhere in Paleogene and Cretaceous deposits) by oxygen dissolved in the water. In deeper parts of the zone, where the oxygen supply has been exhausted, the reverse process of sulfate reduction takes place, carried on by sulfate-reducing bacteria which abound in Mesozoic-Cenozoic waters. As a result of this process, the waters are enriched in HCO_3 ions. First slight evidence of the sulfate reduction has been noted in the Barnaul boreholes which release waters from continental Oligocene deposits with a hydrogen sulfide content up to 1 mg/liter.

The third geothermal zone has a somewhat smaller area than the second one. This zone is missing east of Len'ka settlement, south of the Klyuchi-Pavlodar line, south of Kurgan, and in the peripheral parts of the west Siberian artesian basin adjoining the eastern slope of the Urals and the western edge of the Siberian platform. Its average thickness is 600 m, increasing to 700 or 800 m in the east and decreasing to 300 or 400 m in the near-Uralian part of the basin (Turinsk-Kuznetsovo). In central parts of the basin, the lower boundary of this zone lies at 1200 to 1400 m below sea-level dipping to 1700 or 1800 m in the east, and rising to 600 or 800 m in the northwest (Kuznetsovo). This zone embraces most of the Aptian-Cenomanian aquifers, with the Neocomian and Jurassic along the basin's periphery.

This zone is most favorable for the development of biochemical processes. Such processes as the reduction of sulfates, methane generation, and the accumulation of biochemical nitrogen run out their course, mostly to a termination.

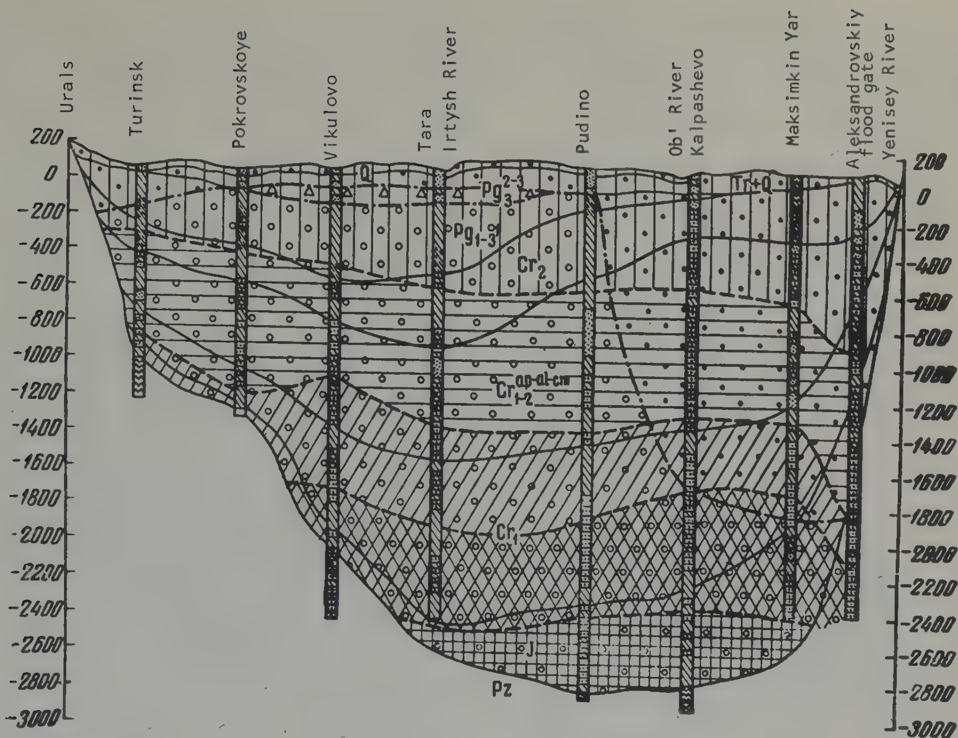

FIGURE 3. Geotemperature gradient along Turinsk - Tara - Maksimkin Yar section. Symbols the same as in Figure 1.

Biochemical processes are caused by various groups of bacteria inhabiting ground water of the West Siberian artesian basin and especially its third geothermal zone whose temperature conditions are favorable for their development. Present here are the sulfate-reducing, denitrating, naphthenic acids reducing, and other groups of bacteria [2]. It has been noted that sulfate-reducing bacteria are developed mostly in areas adjacent to watersheds (Maksimkin Yar, Omsk, etc.), i. e., adjacent to areas of the distribution of sulfate ion-bearing waters. In central areas and in the northwest, where there are no sulfate waters (with only traces of sulfate ions, several milligrams per liter), this group of bacteria is almost absent. In deeper interior parts of the artesian basin, the naphthenic acid-decomposing bacteria predominate (borehole at Pokrovskoye settlement and in other central areas).

As a result of biochemical processes, exchange reactions, and exchange-absorption phenomena, sulfate-hydrocarbonate waters coming in from their sources, undergo a considerable transformation in the third zone: their salt composition changes to the sodium hydrocarbonate. In the lower reaches of this zone, these waters commingle with previously accumulated calcium-sodium chloride (chlorecalcium) waters carrying nitrogen-methane to methane solution gas. The mineralization of ground water in this zone ranges from 1 gm/l. at the source to 20 gm/l. in central parts of the basin.

The temperature conditions of the third and especially the fourth, fifth, and sixth geothermal zones discussed below should promote the extraction of organic material from the rocks and its transformation into gaseous and liquid hydrocarbons. A sharp lowering of the viscosity of water with a rise in temperature creates conditions favorable for a greater mobility of the aqueous solutions and their organic content which, in the presence of traps (both sedimentary and structural), may form oil and gas pools.

The boundary of the fourth geothermal zone is approximately as follows: between Lar'yak and Kellog settlements, in the east; between Belogorka settlement and the town of Mariinsk, in the southeast; along the line Ubinskaya — Karasuk — Gan'kino — Zavodoukovsk, in the south and southeast; and along the line Turinsk — Kuznetsovo, in the west. This zone has not been identified in the Ust'-Port area. Its thickness in central parts is 500 to 600 m, decreasing to 300 or 400 m in the northwest and southeast. It includes the lower part of Aptian-Cenomanian

deposits and the upper Neocomian. Along the periphery of the basin, especially in the southeast, this zone crosses Jurassic coal-bearing deposits with a higher heat resistance which probably accounts for a local thinning of the zone. Its thinning in the northwest is connected with the influx of warm water from central parts to the area of buried outlets. The base of this zone, in central parts of the basin, lies at 1800 to 1900 m below sealevel, rising to 1600 or 1700 m below sealevel in the northwest and southeast. In the Yenisey segment, the base descends to 2000 to 2100 m below sealevel. The principal types of formation waters in this and the underlying zones are nitrogen-methane and methane-calcium with a mineralization of 10 to 56 gm/l.

The boundary of the fifth geothermal zone passes between Lar'yak and Kellog settlements, in the east; somewhat north of Belogorka, in the southeast; approximately along the line Barabinsk — Kupino — Vikulovo, in the south and southeast; and near the line Leusha — Malyy Atlym, in the northwest. This zone appears to be missing in a large area of the North Yenisey trough, except perhaps in its deepest reaches. It is 600 to 700 m thick and includes the lower part of the Neocomian and the top of the Jurassic; the zone base lies at an elevation of 2400 to 2600 m below sealevel.

Finally, the sixth and the lowest geothermal zone with temperatures over 100°C passes a Jurassic water-saturated complex and is traceable in the pre-Mesozoic basement, below. The thickness of this zone from its top to the pre-Jurassic basement ranges widely, from 100 to 700 m, because of the uneven surface of the basement. The approximate boundary of this zone passes between Lar'yak and Kellog, in the east; north of Terul'det settlement, in the southeast; between the towns of Tatarsk and Kupino, in the south and southeast; on to a point north of Vikulovo and farther northwest by way of Malyy Atlym settlement. This zone is probably missing in the North Yenisey trough.

This description of these geothermal zones demonstrates that the position of their boundaries is affected mostly by hydrodynamic and climatic factors. In source areas and in permafrost areas, the zone boundaries are lower. In areas of buried outlets of ground water, chiefly to the northwest, the dividing surfaces are higher.

The effect of tectonics on the position of the zone boundaries also should be noted. For example, a temperature of 117 to 118.5°C was measured at a depth of 2230 to 2295 m in boreholes 3-P and 4-P, the Tobol'sk area, in extrusive rocks at the uppermost pre-Jurassic basement.

Nowhere else in West Siberia has such a high temperature been measured at that depth. These boreholes are located on top of a major structural bench in the pre-Jurassic basement. It is possible that superheated waters rise to the basement surface, thus causing a sharp rise in the upper surface of the sixth geothermal zone (Figure 2).

It is interesting to trace the diminution of the water exchange intensity with depth, which is well illustrated in subsurface maps for various depths (Figure 4). This is suggested by the decreasing number of geothermal zones at each consecutive depth and the smaller area of low temperature zones. Thus, three geothermal zones are present at 1000 m below sealevel, with the predominant 25 to 50°C zone taking in the central areas. A xone with temperatures below 25°C is located in the southeast and east, in the source area; and an outlet zone with temperatures of 50 to 75°C in the northwestern part of the basin. At the same time, almost the entire area at a depth of 2500 m below sealevel is taken over by a geothermal zone with temperatures over 100°C, with a small 75 to 100°C fringe in the east. These maps demonstrate that the cooling effect of downward infiltrating waters in areas of the main source and along the basin's periphery is felt at depths over 2500 m.

The intensity and depth of cooling is a criterion of the magnitude of the water source. It can be stated in this connection that the most potent in the west Siberian artesian basin are the Chulym-Yenisey trough watersheds which replenish the bulk of the ground water. The second major watershed is the Irtysh trough area whence a mighty flow of ground water proceeds northward. All other watersheds can be regarded as secondary and local (the northern part of the Turgai trough, eastern slopes of the Urals, etc.).

That mobile geotemperature equilibrium which has been established as the result of a gradual growth in the porous Mesozoic-Cenozoic section and of the change in paleogeographic conditions prevails in the artesian basin at the present time.

The growth of this section was accompanied by a gradual temperature rise at the surface of the sinking pre-Mesozoic basement. On the basis of the geothermal step as determined by us, this temperature rise can be assumed to be close to 3 to 5°C for each 100 m of porous rocks.

The changing paleogeographic conditions, too, should have affected the temperature distribution throughout the basin. A difference in climate and a change from continental to marine sedimentary conditions were the main factors.

According to V.P. Kazarinov [3], the Mesozoic-Paleogene climate changed from temperate-warm to tropical. It may be assumed

FIGURE 4-a. Geotemperature map showing temperature zones in the area of Mesozoic deposits at a depth of 1000 m below sealevel. By B.F. Mavritskiy, 1958.

1 - boundaries of geothermal zones; symbols the same as in Figure 1; 2 - boundary between waters with mineralization above and below 3 gm/ 1. (calcium chloride waters with a mineralization of 20 to 45 gm/l are developed over the entire area of Jurassic rocks at -2500 m, Figure 4-b. Areas of distribution of Mesozoic deposits: 3 - Aptian-Cenomanian; 4 - Valangian-Barremian; 5 - Jurassic; 6 - boundaries of the pre-Mesozoic basement outcrops; 7 - main direction of the migration of ground water; 8 - borehole temperature at the map level.

then that mean annual temperatures on the site of this artesian basin ranged from 10° to 25°C. Inasmuch as temperature of the normal layer, the one below which a gradual temperature rise with depth begins, is assumed to be the mean annual air temperature or else only 1 or 2°C higher, the first below-surface zone in the Mesozoic and Paleogene was the 0 to 25°C zone. In a period of tropical climate (e.g., Eocene), the first below-surface zone was that of 25 to 50°C.

On On the basis of the climatic conditions and the thickness of the porous section, it may be assumed that all but the first (below 0°C) of our geothermal zones were present in the west Siberian artesian basin toward the end of the Paleogene.

From the end of the Oligocene on, the continental period of basin development witnessed a gradual cooling of climate, which led to the Quaternary glaciation and thick permafrost.

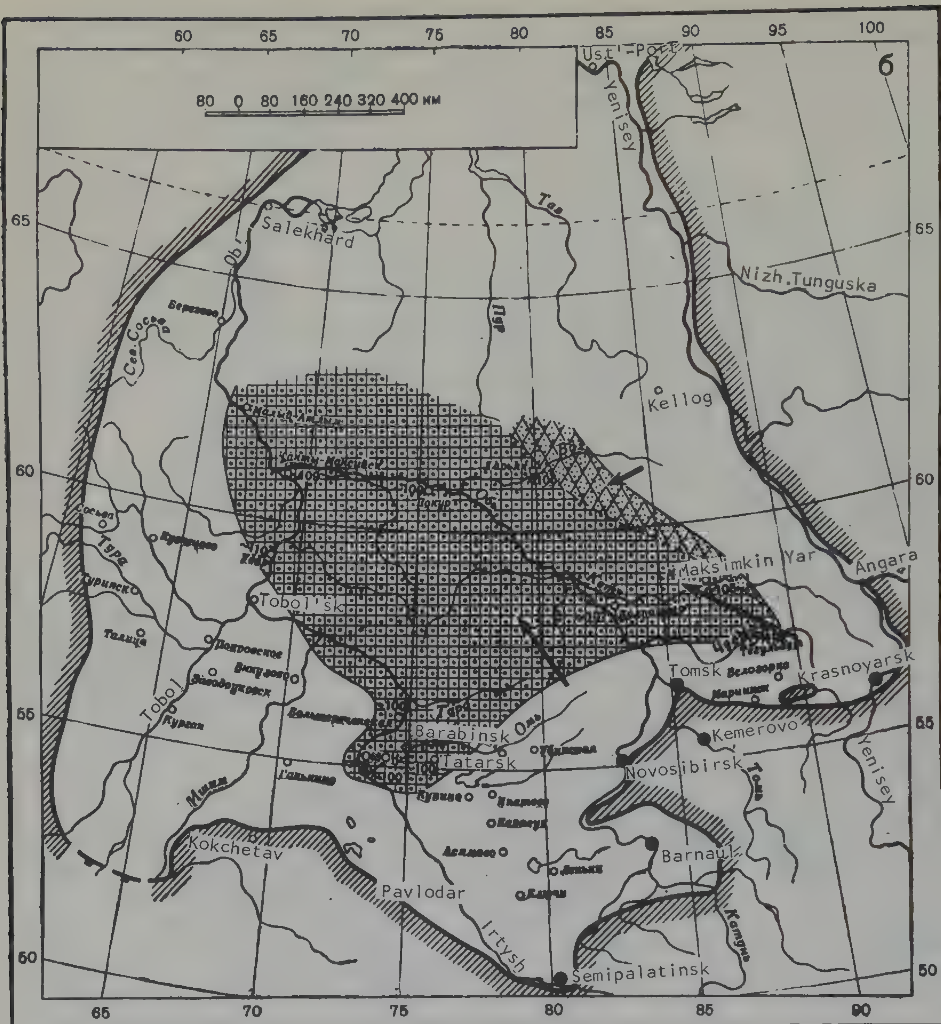

FIGURE 4-b. Same as 4-a, for a depth of 2500 m below sealevel.

A geothermal zone appeared then with temperatures below zero.

The change from continental to marine sedimentary conditions, too, should have affected the temperature conditions. In the period from Early Jurassic to Early Oligocene, shallow epicontinental seas overran on many occasions some of the West Siberian plain, sharply curtailing the ground-water exchange. The penetration of infiltration waters into submarine rocks was limited to the littoral zone. By the same token, a sea basin protected deeper rock horizons from the cooling effect of infiltration waters.

The waters of mobile shallow epicontinental seas, with their temperature close to the mean annual air temperature, could not have exercised the same cooling influence as did the waters of deeper oceanic basins, with their temperature close to zero, on submarine rocks [1].

As the result of this combined effect of climate and epicontinental sea basins, a gradual warming appears to have been imminent in the depths of the interior, because of the heat from the interior of the earth, not fully dissipated through the porous body having a considerable heat resistance. In the Neogene and Quaternary, this warming up gave place to a cooling because of the deep penetration of cold climatic waves and cold seepage waters. Figure 5 shows the contemporaneous temperatures at the pre-Mesozoic basement surface.

We have attempted to demonstrate in the west Siberian artesian basin the complex relationship between the subsurface temperature distribution and its geologic structure and history and hydrodynamic and climatic factors.

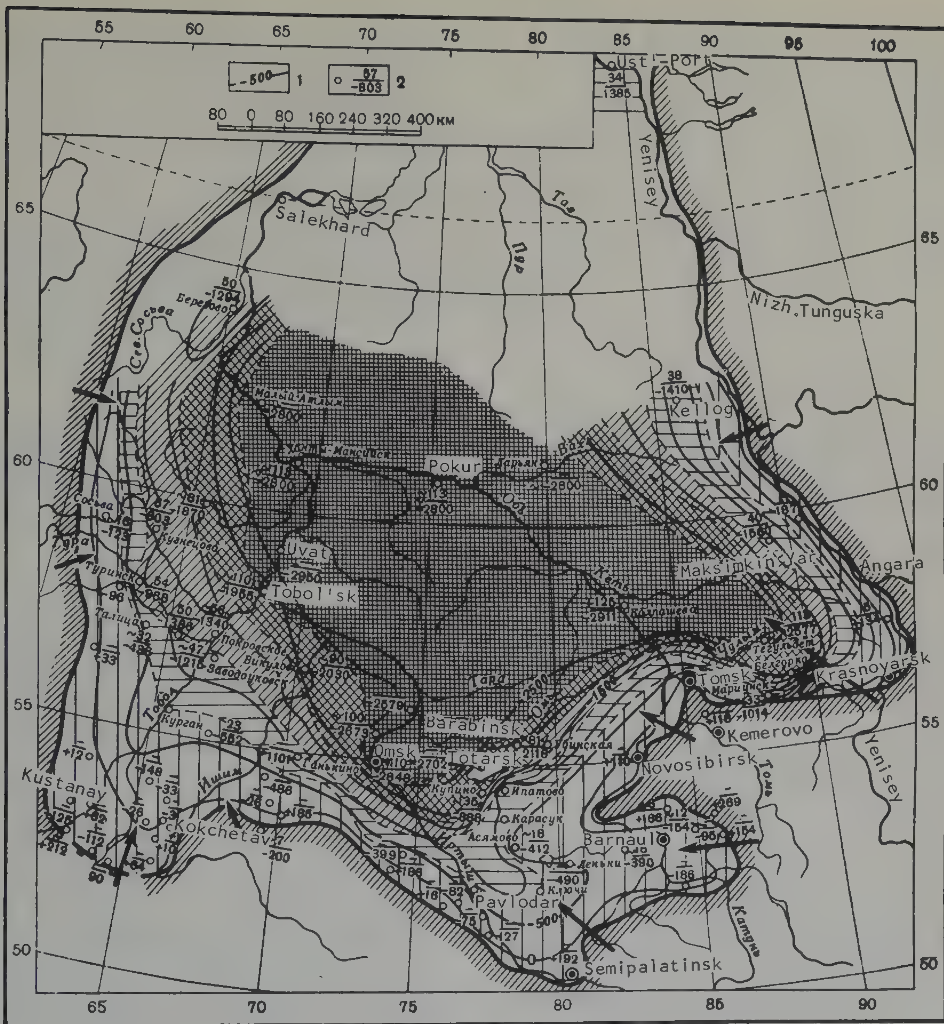

FIGURE 5. Distribution of geotemperature zones at the pre-Mesozoic basement surface. By B.F. Mavritskiy, 1958.

Symbols for geotemperature zones, their boundaries, direction of the water migration, and pre-Mesozoic basement outcrops, are the same as in Figure 1 and 4; 1 - sub-sealevel contours on pre-Mesozoic basement; 2 - nominator, temperature in C°; denominator, sub-sealevel datum for pre-Mesozoic basement.

We have shown that the penetration depth of the surface thermal rhythms exceeds two kilometers, which once more confirms the earlier opinion of many students [5, 7, 8] on a deep penetration of cooling and heating of surface as an effect of climatic and hydrogeologic factors.

Our analysis of the temperature conditions in the west Siberian artesian basin reveals an immense store of thermal waters in its deep interior, amounting to several tens of thousands cubic kilometers (over 65,000 m^3), a very approximate estimate. These waters can be widely used for therapeutic purposes as well as for heating cities, workers' settlements and agricultural centers, heating of green- and hothouses, and for other agricultural and industrial purposes. The most important west Siberian thermal waters occur in Aptian-Cenomanian, Neocomian, and Jurassic deposits.

The most promising area is that limited by the Lar'yak meridian in the east; by the latitude of Belogorka in the southeast; by the Karasuk latitude in the south; by the meridan of Talitsa

settlement and the town of Turinsk, in the west; by the Berezovo area in the northwest; and by the Ust'-Port area in the northeast. Everywhere within that outline, water with temperatures from 40° to 100°C and better can be obtained at depths of 1000 to 2500 m.

Oil and gas deposits may be encountered in hydrothermal zones four, five, and six. One such field has been discovered in the Berezovo area.

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SOME FEATURES OF THE HISTORY OF THE DANKOVO-LEBEDYAN' BASIN[1]

by

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On the basis of a detailed correlation of the Dankovo-Lebedyan' sections in the central part of the Russian platform, the author describes the changes in the salinity of its waters, its assemblage of living organisms, and the type of deposits, from the southwestern and northwestern shores to the center of the basin. The history of development of the basin is also described by short time intervals, along with some regularities in that history.

* * * * *

The Dankovo-Lebedyan' basin has on many occasions attracted the attention of geologists; descriptions of it are found in a number of works (3-6, 11, 16-17, 19-21).

This paper is the first attempt to subdivide the history of the Dankovo-Lebedyan' basin in the central part of the Russian platform by the short time intervals corresponding to the stratigraphic units present in the central field. Noted for each stage of history are the approximate position of the shore line, the area and depth of the basin, as well as the elevation of the source area, as compared with the same data for the preceding period; the salinity of water, the features of its organic world, and the nature of sediments. Also presented are the changes in all these features away from shores and in the course of deposition.

The accuracy of stratigraphic correlations is different for different parts of this area and for different intervals of its composite section.

A number of formations in the central Devonian field, the Lebedyan', Mtsensk, Kudeyarovo, and Ozersk, are characterized by a brachiopod fauna, identified and monographically described (chiefly from our collections) by P. P. Liyepin'sh [7] and A. I. Lyashenko [9]. Lebedyan', Turgenevo, and Ozersk series are described from spore assemblages (also our collections) by S. N. Naumova. The Kiselev-Nikol'skoye formation is identifed by its position in the section; the Khovansk formation, unlike the others, carries remains of characeae algae described by L. M. Birina [1]. Facies changes here were traced by almost unbroken correlation of sections, formations, and at times even of individual beds, over large areas. The accuracy of correlation for the Dankovo-Lebedyan' by formations and members, in the central Devonian field, is unquestionable.

All formations are identifiable with sufficient accuracy, lithologically and partly paleontologically, in most sections throughout the entire western part of the Moscow synclise and its northwestern, western, and southern slopes (Ryazhsk, Stalinogorsk, Tula, Serpukhov, Kaluga, Baryatino, Moscow, Redkino),[2] except for the extreme northwestern and western belts as shown on maps, where these beds are wholly terrigenous or nearly so. There, the formations are identifiable only very tentatively or not identifiable at all. More or less similar sediments are indicated for all such points, on all maps.

Direct correlation of the Dankovo-Lebedyan' sections from the large central part of the Russian platform (boreholes Serdobsk, Nepeytsinsk, Shary'insk, Vozhgal'sk, etc.) with similar sections from the central field is made difficult by facies differences. The Orel-Saburovo member does not carry any sandy material here.

The Mtsensk and Kudeyarovo formations consist mostly of dolomite differing little from those in other formations. Vugs are but slightly developed in them or else altogether missing; as a rule, they carry no fossil fauna. A correlation is possible, however, by means of intermediate boreholes, from lithlogic features, and partially by spores. As such, it is

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[1] Nekotoryye cherty istorii Dankovo-Lebedyanskogo basseyna.

[2] Data from 46 boreholes were used for this paper. Many of them are not shown on litho-facies maps, to avoid confusion.

less detailed and less reliable than for the above-named area nearer to the basin shore.

In some boreholes, the subdivision of some formations is tentative. This, however, does not bar their inclusion in the area shown on maps, because almost all of Dankovo-Lebedyan' time here was marked by the deposition of sulfate and dolomitic sediments, with some changes in their quantitative relationship in the course of time. In other words, in places where the Dankovo-Lebedyan' sections are lithologically similar, unfossiliferous, and consequently are not subject to a detailed and substantiated subdivision, as yet (the central and the northwestern littoral parts of the basin), such a subdivision is not necessary in the making of litho-facies maps, by formations, because the very homogeneity of a section assigns it to the same facies zone. For the rest of the province, where the conditions changed frequently and radically during Dankovo-Lebedyan' time, such changes were reflected in the lithology, which allows a detailed subdivision of the section. Thus, our maps reflect the degree of stratigraphic subdivision, different for different areas.

For example, the eastern, near-Volga part of the province under study, very different from the western in facies, affords but a very rough and tentative subdivision of the Dankovo-Lebedyan' beds into two sections: the lower, represented by dolomite, locally with small amounts of sulfates and almost barren of organic remains; and the upper, made up of limestone and calcareous dolomite with remains of brachiopods, gastropods, pelecypods, ostracods, foraminifera, and algae. The first section corresponds to the Lebedyan' — Kiselev-Nikol'skoye interval of the central field; the second, to the Turgenevo through Khovansk interval. However, some features of individual formations are apparent even here. In the Ul'yanovsk area, the upper part of the Lebedyan' sequence (judging from its position in the section) carries intercalations of sulfates, thereby differing sharply from its sulfate-free lower half.

The wide distribution of standard facies in these beds suggests that our interpretation of their facies composition is generally correct. The subdivision of facies zones by depth is tentative because of the lack of appropriate, strict criteria.

We turn now to the description of basins.

In Lebedyan' time. The following phenomena have been observed in the transition from the Yeletz beds to the Lebedyan' formation:

1) a sedimentary break and erosion of the Yelets deposits in the central and main Devonian fields, in adjacent areas, and in the southern part of the Tokmovo arch;

2) a change from carbonate to terrigenous rocks (in the littoral zone), from dolomite to limestone, and from sulfate-bearing dolomite to dolomite (away from shore).

It can be assumed, therefore, that at the beginning of Lebedyan' time the epicontinental basin of the central part of the Russian platform grew larger and again invaded a part of the previously dried-out land. This resulted in a greater amount of terrigenous material coming from the eroded littoral Yelets deposits, and in a lower salinity of the basin water. These changes can be explained by a subsidence of the basin bottom and adjacent land and by the influx of normally-saline sea water from the south and southeast. The salinity of littoral waters was lowered also because of the influx of fresh river waters.

The subsequent subsidence and widening of the Lebedyan' basin led to inundation of the Lebedyan' area in the central Devonian field and of the southern part of the Tokmovo arch. This transgression reached its maximum in the middle of Lebedyan' time when the central field and the adjacent area to the northwest was a site of deposition of thick, spotty dolomitic limestone similar to the Yelets limestone. Even at that time, this basin remained a part of the Yelets basin.

A litho-facies map for post-Lebedyan' time (Figure 1) shows the following distribution of facies zones:

1. From south to north, from the Serdobsk area to the central part of the map, there is a gradual increase in salinity of the basin, expressed in the change from calcareous dolomitic to dolomitic sediments, and to sulfate-bearing dolomitic farther on.

2. Area of the sulfate-bearing dolomitic sediments accumulation has shifted northward with relation to its position at the close of Yelets time, corresponding to the direction of lower Lebedyan' transgression.

3. Two additional zones with a more or less normal marine fauna appeared offshore near the Voronezh massif: 1) calcareous and 2) calcareous to argillaceous sediments. The salinity of these zones, lower than in waters transgressive from the southeast can be explained as an effect of river flows from the Voronezh massif. Commingling of slightly saline waters in the southern part of the basin with river waters could have produced in these two zones an intermediate salinity close to a normal marine salinity and more favorable for marine organisms.

4. A zone of terrigenous deposits was

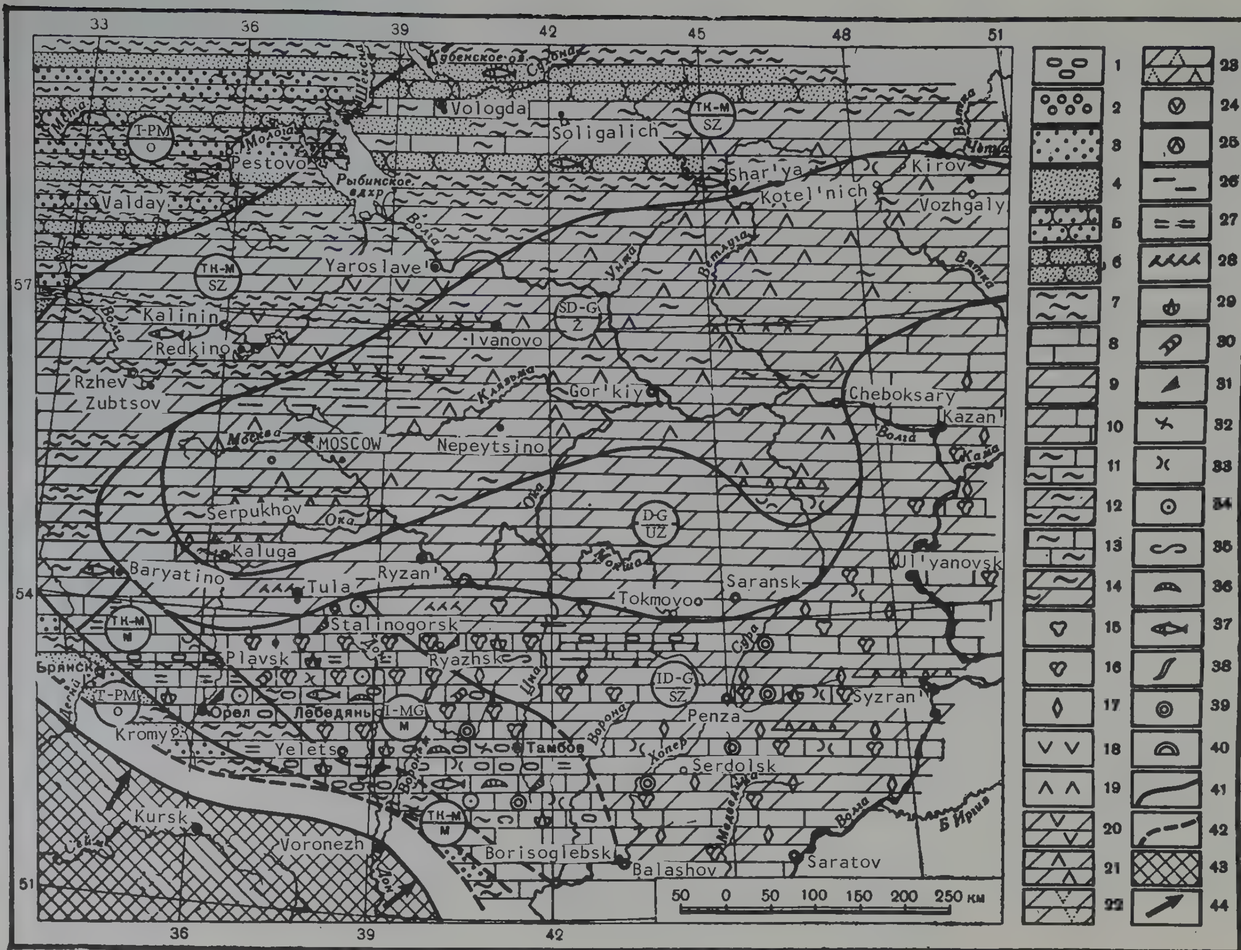

FIGURE 1. Lithofacies map of Lower Lebedyan'.

1 - carbonate gravel and pebbles; 2 - carbonate sandy material; 3 - quartz sand; 4 - silt; 5 - sandstone; 6 - siltstone; 7 - shale; 8 - limestone; 9 - dolomite; 10 - limestone-dolomitic rock; 11 - calcareous marl; 12 - dolomitic marl; 13 - argillaceous limestone; 14 - argillaceous dolomite; 15 - vugs; 16 - dolomitized segments in limestone; 17 - replacement dolomite; 18 - gypsum; 19 - anhydrite; 20 - gypsum-dolomitic rock; 21 - anhydrite-dolomitic rock; 22 - gypsum impregnation in dolomite; 23 - anhydrite impregnation in dolomite; 24 - pocket-like gypsum inclusions; 25 - pocket-like anhydrite inclusions; 26 - banding in dolomite; 27 - organic detritus; 28 - recrystallization; 29 - brachiopods; 30 - nautiloids; 31 - gastropods; 32 - pelecypods; 33 - ostracods; 34 - crinoid segments;35 - serpulids; 36 - stromatoporaroids; 37 - fishes; 38 - worm tracks; 39 - calcifers; 40 - stromatoliths; 41 - boundaries between facies zones; 42 - less definite boundaries between facies zones; 43 - source of sediments; 44 - direction of transportation.

Facies: T) terrigenous; K) carbonate; I) limestone; D) dolomitic; TK) terrigenous-carbonate; ID) limestone-dolomitic; SD) sulfate dolomitic. Symbols in denominator-basin zones according to depth: P) littoral; M) shallow; G) moderately deep; PM) littoral marine; MG) shallow and moderately deep. Salinity zones: O) almost fresh; M) marine; SZ) slightly saline; UZ) moderately saline; Z) saline; L) lagoonal (almost fresh to slightly saline).

located near the southwestern shore; it was probably brachish because the salinity in argillaceous-lime sediments decreased to that of the normal marine state, south of Serpukhov. This conclusion is in accordance with the presence of kaolin intercalations in sandy littoral deposits, in the Kromy area: kaolinite is unstable in a marine environment.

5. The basin salinity also is lower toward the northwestern shore where sulfates are missing in the Lebedyan' section and dolomite replaced by limestone (at Vologda). However, this desalting process is not as well expressed here as on the southwestern edge of the basin, because of the abundance of terrigenous material which does not reflect the salinity stages.

6. A definite asymmetric distribution of terrigenous and carbonate deposits exists with relation to the latitudinal axis of greater salinity of the basin: there is much terrigenous material in the north, with hardly any limestone; but there are many linestones in the south with little terrigenous material. This asymmetry came about in the following way: 1) marine waters responsible for the lowering of the basin's salinity and for the deposition of limes and dolomitic sediments came precisely from the south; their effect did not spread as far as the northern edge; 2) terrigenous material came chiefly from the northwestern source because of its larger area and the terrigenous sedimentary rocks on its surface. Only a small amount of clastic material, mostly sandy, came from the Voronezh massif which apparently had a less developed sedimentary mantle and a comparatively small area. Another factor was the arid climate of the time, which hampered the processes of chemical weathering and the formation of clays.

7. The asymmetry of facies profile of the basin along line the Baltic shield — Moscow — Voronezh massif, is expressed also in the greater width of facies zones (as well as in the greater intervals between adjacent isopachs, not shown on the map in order not to confuse them with the facies boundaries) in its northwestern part compared with the southern. That has been brought about by a larger volume of river water and terrigenous material coming from the northwest compared with that from the Voronezh massif. That explains also the asymmetric position of the maximum salinity in the west of the basin where it approached the Voronezh massif.

In the second half of Lebedyan' time, the basin gradually became more shallow, smaller, and more saline. Limestone-dolomitic, and locally pure dolomitic shallow-water facies were deposited in the area of development of the Yelets-type limestone. Elements of a stenohaline fauna, brachiopods, nautiloids, and crinoids, are missing here. The zone of deposition of dolomitic sulfate sediments extended in all directions, especially to the southeast, as far as the Kuybyshev Volga region. All other zones became correspondingly narrower and shifted landward. A higher salinity of the basin was determined by its more pronounced isolation brought about by an uplift of the bottom, under arid conditions. This regressive process attained its maximum at the close of Lebedyan' time when coarse clastic carbonate material was deposited in the vast littoral zone of the basin with the formation of serpula and algae bioherms.

Thus the Lebedyan' basin expanded and dilated in the course of its existence; accordingly, the Lebedyan' sequence represents an independent sedimentary cycle.

Mtsensk time. A reconstruction of the history of the Dankovo-Lebedyan' basin for this period presents great difficulties because of the Mtsensk series is thin over a greater part of the area and for that reason is not represented in cores and cuttings from some of the boreholes. Still, its characteristic features stand out quite clearly on a map of Mtsensk time.

In the central Devonian field and the vast adjacent area (from Stalinogorsk to Baryatino), the Mtsensk series consist almost fully of thick-bedded, monotonous cavernous replacement dolomites with local spotty-dolomitic limestones (Figure 2). In the Orel area it opens with a brachiopod "shell" bed and maintains this character in its extreme southwestern outcrops where the Lebedyan' series underlying it is represented by sand. The limestones and dolomites carry a fairly diversified brachiopod fauna, crinoid segments, and isolated remains of gastropods and nautiloids. In the Soligaluch-Redkino zone, the Mtsensk carbonate rocks rest on terrigenous and carbonate Lebedyan' rocks; northwest of Pestovo, the Mtsensk terrigenous carbonate rocks are underlain by pure terrigenous Lebedyan' rocks.

It follows that in Mtsensk time this basin deepened and widened and its salinity increased although not up to normal marine salinity. The widening of the basin was slight, judging from the rapid thinning of the Mtsensk sequence south of Orel. All this was due to a subsidence of the basin bottom and to the influx of normal marine water from the southeast. However, the salinity soon started to rise again, as witness the increase of dolomite and an improverishment of the fauna, going up the section: the subsidence gave place to an uplift.

In the littoral zone of the basin (the Orel area), the decrease in salinity was at its maximum in the beginning of Mtsensk time, and at its minimum at the end of it. The latter is corroborated by the repeated appearance here

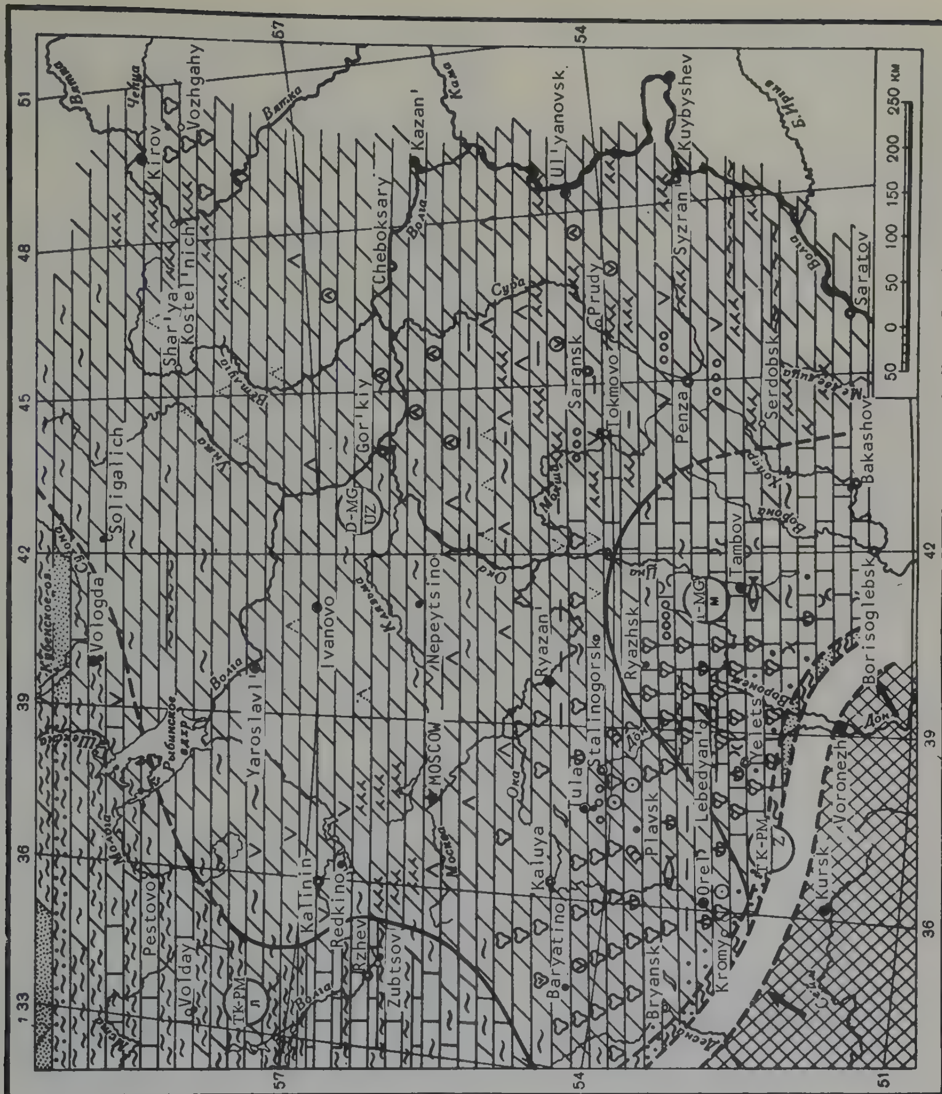

FIGURE 2. Lithofacies map of Mtsensk time. Symbols the same as in Figure 1.

of an impoverished brachiopod fauna in the upper part of the sequence; but it is totally lacking in the middle part. This can be explained by an approach of the shoreline to the Orel area, at the beginning and the end of that time, which increased the influx of river water, in that locality. This factor was more potent at the beginning of Mtsensk time than at the end of it because first of all, it operated on the background of a lowering salinity due to the influx of marine water into the Dankovo-Lebedyan' basin; secondly, it operated against a general (in the basin as a whole) rise in salinity. It follows that the Mtsensk sequence, too, may be regarded as an independent sedimentary cycle.

North of the central field and the southern part of this area, these features of the Mtsensk series gradually disappear, because that was the direction of a weakening of the effect of the incoming marine water. In addition, in the northern and northwestern reaches of the basin, with the freshening effect of rivers, carbonate sediments were highly contaminated with terrigenous material. Because of that, the vuggy dolomite facies is missing here.

In the Mtsensk basin, the zone of pure terrigenous sediments was very narrow if not altogether missing; the zone of terrigenous-carbonate deposits, located near the northwestern source area, contracted and shifted landward, with its terrigenous material represented chiefly by clay; the central zone of carbonate and sulfate sediments widened while its sulfate

content decreased considerably. These changes and shifts in facies zones, too, suggest a Mtsensk transgression.

The Kiselev-Nikol'skoye time. In and about the central Devonian field, the greater middle part of the Kiselev-Nikol'skoye interval is made up of monotonous light-yellow, banded primary dolomite with intercalations and lenses of altered dolomite formed from mixed sulfate-dolomite rocks [12]. Stromatoliths are widely distributed in its lower part formed chiefly by similar, banded dolomites, with numerous worm tracks and molds and impressions Arca oreliana Vern, occurring locally in bedding planes and in isolated thin lentils. The upper part of this sequence is represented in the littoral zone chiefly by arenaceous rocks changing to assorted shallow-water dolomites away from shore: clastic, oölitic, stromatolithic, containing serpulrids, and pelecypods. An erosional surface has been observed locally between the Kiselev-Nikol'skoye and Turgenevo beds. This series persists as far as the Mtsensk to the southwest.

Sections in the central part of the basin present the same alternation of banded dolomite, sulfate, and dolomitic sulfate rocks.

The lithofacies map of Kiselev-Nikol'skoye time (Figure 3) shows that the terrigenous-carbonate zone in the northwest part of the basin shifted toward the center, while the central dolomitic sulfate zone was widening to the southwest, from Serpukhov almost as far as Orel. The zone of calcareous deposits near the Voronezh massif narrowed correspondingly.

It follows, then, that during most of Kiselev-Nikol'skoye time the basin salinity was considerably higher then in the preceding Mtsensk time, while its depth and area were only slightly smaller. However, at the beginning of that time and especially toward the end of it, the basin was considerably shallower, and toward the end its littoral zone became dry land. Thus the Kiselev-Nikol'skoye series, too, represents a sedimentary cycle reflecting a full subsidence-uplift oscillation of the crust. In addition, it is a culmination of the larger Lebedyan' — Mtsensk — Kiselev-Nikol'skoye cycle which corresponds to a larger and longer oscillation of the crust. The Mtsensk series corresponds to the middle of that larger cycle (maximum subsidence); the Lebedyan' series corresponds to its beginning.

The Orel-Saburovo interval within the Dankovo-Lebedyan' is sometimes identified in the central Devonian field. A closer study reveals, however, that this interval, unlike the others, is not an independent sedimentary cycle but is formed rather by adjacent intervals of two large sedimentary cycles: the top of the Kiselev-Nikol'skoye and the base of the Turgenevo. For that reason, this interval should be taken out of the stratigraphic classification for Upper Famennian deposits in the central part of the Russian platform. Being the shallowest-water interval in the section, it is very conspicuous, however, in its lithologic features, not only in the central field but far beyond it, and its presents a very convenient marker for a division of the cycles.

This paper describes the Kiselev-Nikol'skoye and Turgenevo series as including the corresponding portions of the "Orel-Saburovo" interval.

The history of the Dankovo-Lebedyan' basin during the second half of its life, corresponding to the Turgenevo - Khovansk sequences, is similar to that for Lebedyan' -Kiselev time, as witness the clear division of the Dankovo-Lebedyan' section into two similar sedimentary cycles. Accordingly, we shall mention only some outstanding features of that time.

The Turgenevo basin was similar to the Upper Lebedyan', but smaller and more saline. The most significant event of that time was the cessation of sulfate deposition in the vast northeastern part of the basin (except for the Penza-Syzran' area where it went on), which was not revived till the close of the Devonian. A revival of the basin started in that province, a lowering of its salinity gradually spread northwest.

The Kudeyarovo basin was similar to the Mtsensk but smaller. In the Orel area, its shoreline receded some 40 km relative to its Mtsensk position. His brachiopod fauna was more monotonous than the Mtsensk.

The Ozersk basin shows the most similarity with the Kiselev-Nikol'skoye, although it was even more saline in its central part, northwest of the Ryazhsk — Gor'kiy — Cheboksary line. A thick sequence (up to 20 m) of almost pure gypsum was deposited locally, at that time.

The Khovansk basin differs from the others in many respects and shows some similarity only with the Orel-Saburovo basin. We shall describe some of its detail.

1. Its boundaries did not extend beyond the Ozersk basin; most likely, it lay fully within the latter. A definite solution of this problem is difficult because of post-Devonian erosion of the Khovansk interval.

2. Its depth was shallow, as witness the wide development of oölites, stromatoliths, and root tracks of terrestrial plants in rocks of the central field, as well as of clastic carvonate material, ostracods, serpulids, and fishes, away from the shores.

3. The degree of salinity of this basin is of great interest because of its close relationship

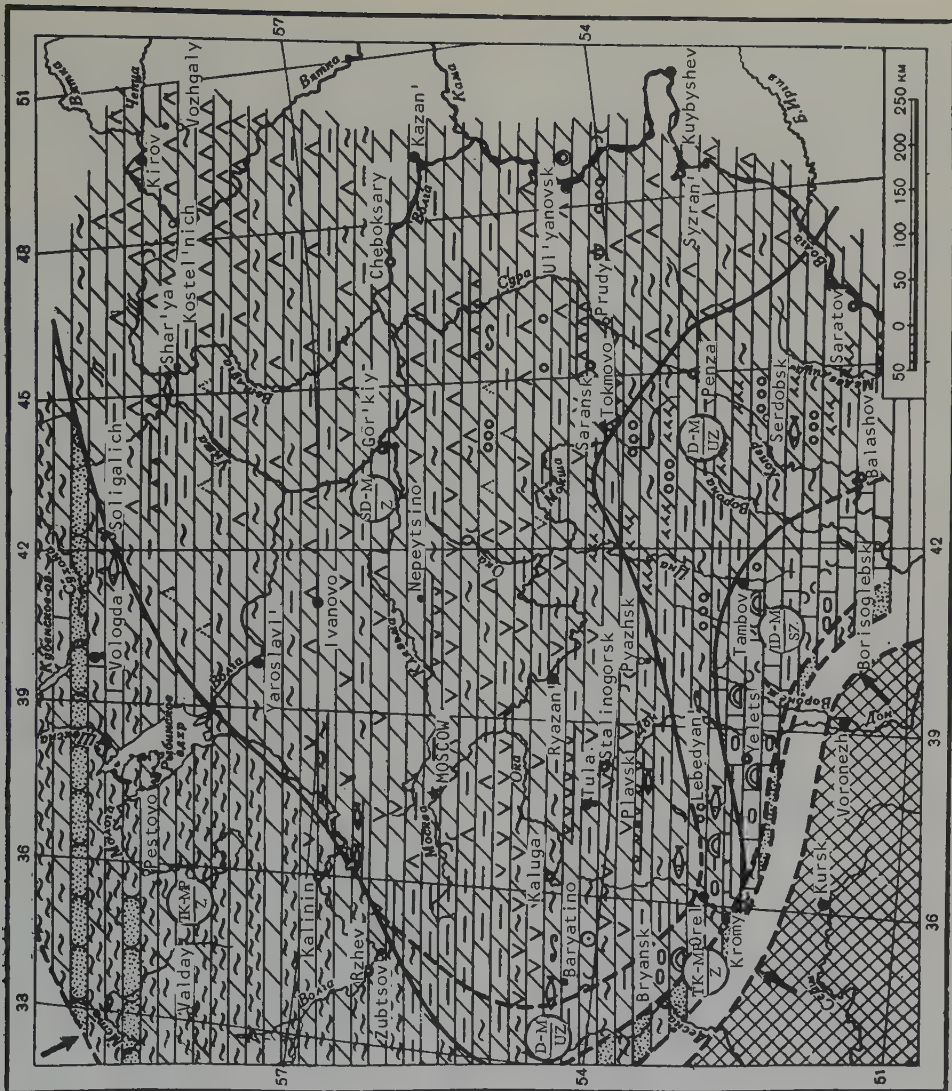

FIGURE 3. Lithofacies map of Kiselev-Nikol'skoya time. Symbols the same as in Figure 1.

with the Khovansk climate, the organic world in the basin, the regressive vs. transgressive nature of this sequence, and its Devonian vs. Carboniferous age. Published data on this subject are contradictory [18, 21]. Our own observations and conclusions can be summed up as follows:

1) there is no definite evidence of an Ozersk – Khovansk break. On the contrary, in the central field the Ozersk sequence gradually changes to the Khovansk;

2) in many sections, the Khovansk sequence carries dolomite; locally (in the Kotel'nich area) it is fully dolomitic, with the dolomite content increasing to the north and northeast of the Voronezh massif, as is also true for the underlying sequences.

It follows that this basin developed from the Ozersk, undoubtedly a very saline one. This is indirect evidence of the high salinity of the Khovansk basin, at least in some parts of it, at the beginning of Khovansk time. A direct proof of its higher salinity, in some parts and during all or some of Khovansk time, is the above-mentioned wide distribution of dolomite throughout the Khovansk section.

The cessation of deposition of sulfates and a continued deposition of calcareous dolomitic

and lime sediments over vast areas of Ozersk dolomite deposition suggest a considerable salinity decrease in the Dankovo-Lebedyan' basin in Khovansk time (locally, apparently below the normal marine), as compared with the Ozersk. This probably was brought about by an uplift in the sedimentation and the source areas, which increased the flow of river water into the basin and reduced the volume of its saline waters inherited from Ozersk time. The salinity of the latter was thus considerably reduced. It is quite probable that this process was assisted by a contemporaneous increase in humidity, which is corroborated by S.N. Naumova's data [15] on the hydrophilic nature of spores from the Khovansk section in Kirovskaya and Kalininskaya Oblast'.

Having acquainted ourselves with the stage-by-stage history of the Dankovo-Lebedyan' basin, we turn now to some general features and regularities in its evolution.

1. In all maps, the shoreline of this basin lies the zero isopach because all intervals have been eroded to a variable extent, along its periphery. Some of this erosion took place in the Famennian when the littoral zone of the basin stood temporarily high; most of it occurred, however, in post-Devonian time. Specifically, all maps except that of Khovansk time show deposition in the Yeletz area, although only a lower portion of the Lebedyan' section has been preserved there. Its original presence there is substantiated by the thickness and facies character of other series in their southern outcrops, considerably north of Yelets.

Inasmuch as the position of the basin's shoreline at different stages of its development cannot be determined with precision, it is indicated tentatively by a dashed line. Outlined in the same way is the source area in the southwestern part of the map. Very tentatively indicated is the shoreline within the main Devonian field, because of the lack of data. It appears to have been located at times beyond the area indicated on maps. The lack of field data prevented showing of the southwestern reaches of the basin. However, in determining the composition of sediments west of the Baryatino-Zubtsov line, we took into consideration the Smolensk section of the Dankovo-Lebedyan' beds.

2. On some maps, dolomitic sulfate sediments are shown at Plavsk and south of there, although sulfates are missing in that section at the present time. This has been done because of the presence of altered dolomite formed from assorted dolomitic sulfate rocks.

3. The facies makeup of the Dankovo-Lebedyan' basin persisted more or less uniform in time. The changes consisted mostly of shifts in the facies boundaries, in either expansion or contraction of their areas; in the relative content of terrigenous, carbonate, and sulfate fractions; in the quantitative ratio of the argillaceous to the sandy-silty fraction; in the degree of dolomitization; and in the fact that at some stages of development, the extreme members of the facies series, such as dolomitic sulfate or terrigenous, were either missing or else very much restricted in distribution.

4. Both the bottom of the Dankovo-Lebedyan' basin and its source areas were involved simultaneously in the same oscillatory movements, as witness the following observed facts. A deepening and widening of the basin was not accompanied by an increase of incoming terrigenous material, as should have been the case in a simultaneous uplift of the source area. The opposite was true. On the other hand, an increase in the amount of incoming terrigenous material (e.g., as in Orel-Saburovo time) was accompanied by a loss of depth not only offshore but out in the basin as well. For example, the Tula area of that time witnessed the appearance of stromatoliths, absent in both the Kiselev-Nikol'skoye and Turgenevo sections. In many other boreholes, that time is marked by an increase in clastic carbonate material and in the size of fragments. An exception occurred during the Khovansk movements when, despite the extreme shallowness of the basin, the amount of incoming terrigenous material was insignigicant.

5. The published data on the presence of islands in the Dankovo-Lebedyan' basin are contradictory. D.V. Nalivkin [14] believes that a terminal Famennian sea on the Russian platform possibly gave rise to an archipelago. In another work [13], he stated that islands are bound to be present in such a sea. M.S. Shvetsov [22], too, believes that the Dankovo-Lebedyan' basin had islands. On the other hand, L.M. Birina [2] speaks of the lack of any evidence of dry land (islands) in the Dankovo-Lebedyan' beds, away from the shores of their basin of deposition. L.S. Petrov [16], too, believes this basin to have been an "open" one.

The consistency in the thickness and lithology of these beds over long distances, as determined from numerous boreholes, suggests, on the whole, an open basin. However, a period of maximum shoaling, with temporary large islands, such as the one located on the site of the southern part of the Tokmovvo arch, occurred at the close of Dankovo-Lebedyan' time; a similar island (peninsula?) existed in the Lebedyan' area, at the beginning of Lebedyan' time. It is possible that other, as yet unknown, islands were in existence at that and in Orel-Saburovo time. A basis for such an assumption is the shallowness of the basin and the local presence of argillaceous and dolomitic sulfate members in corresponding intervals from the central part of the Dankovo-Lebedyan' beds: in the Orel-Saburovo deposits for the first, and in

the Turgenevo and Ozersk deposits for the second.

6. As noted in many publications and confirmed by our own observations, the main source of terrigenous material for the Dankovo-Lebedyan' basin was uplifts north and northwest of there. At the same time, another and smaller source area may be assumed as definitely established, i. e., that of the Voronezh massif near which a large amount of terrigenous material was occasionally deposited (in Lebedyan' and Orel-Saburovo time). We emphasize this because that smaller area is not shown on lithofacies maps for the Famennian of the Russian platforms [8, 16].

Thus the main stages of geologic development of the Dankovo-Lebedyan' basin were as follows: A subsidence, accompanied by that of the source areas (in Mtsensk and Kudeyarovo time) resulted in a widening and deepening of the basin, in the inflow of marine water, a lower salinity, the appearance of a more diversified fauna, the cessation of deposition of sulfates, a widening of the zone of deposition of calcareous sediments, and a decrease in terrigenous material. An uplift of the basin and the source areas (in Kiselev-Nikol'skoye and Ozersk time) brought about a reversal of these conditions.

The freshening effect of rivers in the basin's littoral zone brought about corresponding changes in the organic world and in the composition of sediments. An arid Dankovo-Lebedyan' climate, prevailing between the marine transgressions, determined the high salinity of the basin with all its consequences.

A combined effect of all these factors was the very complex distribution of facies throughout the basin.

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BRIEF COMMUNICATIONS

SELECTION OF THE K^{40} DECAY CONSTANTS IN DETERMINING THE AGE OF ROCKS WITH RELATION TO Ar^{40} AND K^{40}[1]

by L. V. Firsov

I. A comprehensive study of a number of geologic problems is unthinkable at the present time without a mass determination of the absolute age of rocks and minerals by stable radioactive and radiogenic isotopes. The last decade has witnessed the organization of 14 laboratories in the Soviet Union, in most of which, and for most specimens, absolute-age determination is done by the K-Ar method.

An advantage of this method over others (e.g., helium, lead, strontium) lies first of all in its applicability to a wide range of potassium-bearing rocks. It also is much less cumbersome, and a laboratory determination of potassium and radiogenic argon is more accurate than a determination of other isotopes.

Approximately 1 to 2% of all absolute-age determinations are done by the lead method; fewer than 1% by other methods; and 97 to 98% by the K-Ar method. Chances are that this ratio will persist; in any event, there is no reason to doubt it at the present time. The K^{40} isotope whose content in a mixture of K-isotopes in nature is constant, being 0.0119 ± 0.0001 atomic percent [26] or 0.01216% by weight, is radioactive and characterized by double decay: beta decay with the formation of K^{40} and K-capture with the formation of Ar^{40}. If the amounts of K^{40} and Ar^{40} in a rock are known (in grams per one gram of rock), the age of the rock can be computed with the following formula:

$$t = \frac{\log\left(\frac{Ar^{40}}{K^{40}} \cdot \frac{\lambda_k + \lambda_\beta}{\lambda_k} + 1\right)}{(\lambda_k + \lambda_\beta) \log e} \text{ years}$$

where λ_k is the K-capture constant and λ_β is the constant of K^{40} beta decay, both computed on the basis of measurements of gamma and beta activity of K. Precision of this measurement determines the precision of the age determination. However, measurements of gamma and beta activity are not always reliable because of various difficulties involved.

A precise branching ratio of K^{40} decay has not yet been established; however, divergences between its latest determinations do not exceed 10%. Prior to 1959, the following values were used in Soviet laboratories, in the age determinations: $\lambda_k = 0.6 \times 10^{-10}$ year $^{-1}$ and $\lambda_\beta = 4.9 \times 10^{-10}$ year^{-1}, with $\lambda_k/\lambda_\beta = 0.1225$ [1, 13].

In 1959, the Commission for the Absolute-Age Determination of Geologic Formations at the Section of Geologic-Geographic Sciences, AS U.S.S.R., recommended the use of the following values, on the basis of the latest potassium-activity determinations by American investigators (37): $\lambda_k = 0.557 \times 10^{-10}$ year $^{-1}$ and $\lambda_\beta = 4.72 \times 10^{-10}$ year^{-1}, with $\lambda_k/\lambda_\beta = 0.118$. The figures so obtained turned out to be larger by 8%; in a number of cases, especially for the Mesozoic and Cenozoic, they differed substantially from the assumed or determined geologic ages.

German scientists (V. Noddaek and D. Zeitler, 1956) used the values of $\lambda_k = 0.618 \times 10^{-10}$ year $^{-1}$ and $\lambda_\beta = 5.16 \times 10^{-1}$ year^{-1}, with $\lambda_k/\lambda_\beta = 0.120$, etc.

This uncertainty leads to the fact that results of the absolute-age determinations published by various laboratories and individual students often are not correlative, especially since it has become customary to publish the age figures only, without the basic K-Ar data.

A number of authors published resumés on the determination of K activity and K^{40} decay constants [1, 3, 5, 11]. However, some of the determinations were not included or else only partly included.

Given below is brief information on the

[1] O vybore konstant raspada K^{40} dlya opredeleniya vozrasta porod po otnosheniyu Ar^{40} k K^{40}.

measurements of gamma and beta activity of potassium, performed in 1947-1957; new K^{40} decay constants are proposed, the application of which would achieve fair results in determining the rock age throughout an interval of 50 to 500 million years and longer, i. e., in the range of the entire geologic time scale.

II. Direct measurements of gamma activity for potassium, as a result of K capture of K^{40}, were performed on scintillation counters with photomultiplies and Geiger-Müller counters. They gave the following results (in γ/sec. gm K):

E. Gleditsh and T. Graf, 1946 [16]	3.6 ±0.8
L.H. Ahrens and R. Evans, 1948 [6]	3.42±0.07
V.F. Hess and J.D. Roll, 1948 [20]	2.6 ±?
G.A. Sawyer and M.L. Wiedenbeck, 1949 [28].	3.60±?
F.W. Spiers, 1950 [32]	2.97±?
W.R. Faust, 1950 [13]	3.6 ±0.4
T. Graf, 1950	3.4 ±0.5
F.G. Hautermans, O. Haxel, and J. Heintz, 1950 [22]	3.1 ±0.3
P.R. Burch, 1953 [10]	3.37±0.09
A. Suttle and W.F. Libby, 1955 .	2.96±0.3
G. Backenstoss and K. Goebel, 1955	3.50±0.14
A. MacNeyr, P.N. Glover, and H.W. Wilson, 1956	3.33±0.15
G.W. Weatherill, 1957	3.39±0.12

The average value of gamma activity for K, as obtained from these 13 determinations, is 3.295 γ/sec. gm K. However, it cannot be accepted because some of the measurements were made with a possible error of ±10 to 20%. Some of the most accurate measurements are 3.42 ±0.07; 3.37 ± 0.09; 3.50 ± 0.14; 3.33 ± 0.15; and 3.39 ± 0.12. The average of these five determinations is, in round figures, 3.40 γ/sec. gm K, which is close to the latest reliable figure obtained for gamma activity by G. Weatherill.

III. Measurements of K beta activity, because of the great experimental errors, produced values ranging from 22.5 to 34 β^-/sec. gm K:

L.B. Borst and J.Z. Floyd, 1948 [9]	23 ±2
T. Graf, 1948 [18]	26.8±1.2
O. Hirzel and H. Wäffler, 1948 [21].	34 ±4
R.M. Stout, 1949	30.6±2
J.J. Floyd and L.B. Borst, 1949 [14]	25 ±2
W.R. Faust, 1950 [13].	31.2±3
F.G. Hautermans, O. Haxel, and J. Heintz, 1950 [22].	27.1±1.5
G.A. Sawyer and M.L. Wiedenbeck, 1950 [29].	28.3±1
B. Smaller, J. May, and M. Freedman, 1950 [31]	22.5±0.7
M.L. Good, 1951 [17]	27.1±0.6
C.F. Delaney, 1951 [12].	32.0±3
Endt and Kleiver, 1954	27.6±?
A. Suttle and M.F. Libby, 1955	29.6±0.7

The average value of beta activity, as obtained from all 13 determinations, was 28.05 β^-/sec. gm K. However, deviations from this average are too great (over ± 20%) for it to be accepted. In five measurements, the figures differ from each other by a maximum of 1.5 β^-/sec. gm K; they are 26.8; 27.1; 28.3; 27.1; and 27.6 β^-/sec. gm K. The average of these five is 27.4 β^-/sec. gm K, with a deviation of ± 2.75%. The remaining measurements of beta activity are too unreliable. They cannot be grouped into similar groups of five and are obviously erroneous. Specifically, the high values of beta activity appear to have been obtained without due regard to the counting installation, cosmic radiation, etc.

IV. A final selection of the value for beta activity of K should be made on the basis of the computed and directly measured ratios of gamma and beta activities of K: $R = \gamma/\beta^- = \lambda_k/\lambda_\beta$. The 1947-1948 determinations of R are too high, because of imperfection of the apparatus and the failure to consider cosmic radiation:

E. Bleurer and M. Gabriel, 1947 [8]	1.9 ±0.4
L.H. Ahrens and R. Evans, 1948 [6]	0.72±0.2
L.B. Borst and J.Z. Floyd, 1948 [9]	1.4
T. Graf, 1948 [18]	2.45±0.5

At the present time, these erroneous determinations are only of historic interest.

In 1949 and 1950, G. Sawyer and M. Wiedenbeck [28, 29] computed the value of R from the ratio of Auger electrons to beta radiation of K. The probability of the Auger electron expulsion for K^{40} considerably exceeds that for emission of gamma quanta. G. Sawyer and M. Wiedenbeck isolated Auger electrons from beta radiation and correlated it with the gamma activity of K known at that time. They obtained R = 0.135. Correction for the new value of gamma activity gives R = 0.125.

The most numerous and least divergent determinations of the branching ratios for K^{40} decay were performed after 1948, as follows:

O. Hirzel and H. Eaffler, 1948 [21]	0,187
V.F. Hess and J.D. Roll, 1948 [20]	0.100
T. Graf, 1948 [18].	0.11
F.G. Hautermans, O. Haxel, and J. Heintz, 1950 [22]	0.105
F.W. Spiers, 1950 [32]	0.100
T. Graf, 1950-1951 [19]	0.127±0.012
W.R. Faust, 1950 [13]	0.115
P.R. Burch, 1953 [10]	0.127
A. MacNeyr, P.N. Glover, and H.W. Wilson, 1955.	0.121±0.004
Same authors, different method, 1955	0.124±0.002

The most reliable is the last determination by A. MacNeyr, R. Glover, and H. Wilson. An average of four determinations in the 0.121 to 0.127 interval is almost exactly 0.125.

V. Irrespective of the precision of counting instruments, a determination of R is essentially a calculation of the decay constants and consequently of the branching ratio, from the known quantities of Ar^{40} and K^{40} in rocks whose age has been well established. Such determinations are listed below:

L.T. Aldrich and A.O. Nier, 1948 [7]	0.02 -0.10
R.D. Russel, H.A. Shillibeer, et al, 1953 [27]. . . .	0.06
Mousuf, A.K., 1952 [25].	0.066
G.J. Wassenburg and R.J. Hayden, 1955 [34, 35] . . .	0.086
H.A. Shillibeer and R.D. Russel, 1954	0.089
H.A. Shillibeer, R.D. Russel, R.M. Farquahar, and Jones, 1954	0.09
E.K. Gerling, N.Ye. Titov, and G.M. Yermolin, 1949 [2]	0.125
M.G. Inghram, H. Brown, C. Patterson, and D.S. Hess, 1950-1951 [23, 24]	0.122-0.131
G.J. Wasserburg and R.J. Hayden, 1954 [33].	0.13

This method cannot be regarded as reliable, for two reasons. First, the question of a complete preservation of radiogenic argon in rocks and minerals is answered in the negative, at the present time ([1, 7, 36], etc). It is believed that a portion of radiogenic argon escapes from the crystalline lattice of minerals, because of various geologic processes, with metamorphism, in its broader interpretation, foremost among them. Feldspars suffer the greatest lost in radiogenic argon, while micas are capable of preserving all or most of it. This problem, however, is not as simple and unequivocal as it appears to some students. For instance, G. A. Murina [4] has shown in her parallel determinations of age that it turns out to be the same, very often, as obtained either from feldspars or micas, suggesting that there had not been any loss of radiogenic argon in the feldspars. The important fact is that this has been established for rocks 130 to 2060 million years old. Nevertheless, this independent method of determination can be used only when there is absolute certainty that a rock or mineral has not undergone metamorphism which could have disturbed its K-Ar equilibrium. Such certainty is hardly ever realized.

Second, a calculation of R from determinations of radiogenic argon or radiogenic calcium requires not only a knowledge of the precise geologic age of a specimen but a reliable scale of absolute age. The present geochronologic scales (of A. Holmes, J.P. Marble, and L.J. Kulp) differ substantially from one another, which suggests that they are not quite reliable and are in need of further refinement. One way out of this difficulty is to determine the specimens age by other methods (such as the lead method, when minerals containing uranium and thorium are present in the rock; but again one can never be sure that such determinations are correct.

For that reason, most of the above-cited values (in the 0.02 to 0.10 range) are obviously underestimated. They were obtained on specimens which had lost a considerable portion of their argon. On the other hand, independent determinations of R by E.K. Gerling et al, 0.125; and M.G. Inghram et al, 0.122 to 0.131 (average, 0.1265), are in fair accordance with counting experiments. It appears that mineral samples with their full store of radiogenic argon were used in these determinations. E.K. Gerling used the Ar^{40}/β^- method; M.G. Inghram used the Ar^{40}/Ca^{40} method. The latter is fully independent of the measurements of K activity and its age; consequently it may be regarded as the most reliable.

VI. It is expedient, then, to accept (until further refinement) the following values for K activity and the branching ratio of K^{40}:

Gamma activity of K	=	3.40γ/sec. gm K
Activities' ratio	=	0.125
Beta activity of K	=	27.2 β^-/sec. gm K

These values are very close to those accepted in American laboratories where the absolute-age determinations are done with the K-Ar method, in the preparation of a new absolute geochronologic scale (L.J. Kulp, 1959).

The K^{40} decay constant is computed from the following formula:

$$\lambda = \frac{A.B}{C} \text{ year}^{-1}$$

where A is the value of the corresponding K activity; B is 31,536,000 sec., the number of seconds in a year; and C is the number of K^{40} atoms in 1 gm K, with the atomic weight of K = 39.1, the Avogadro number 6.02×10^{23}, the K^{40} content in a mixture of K isotopes, 0.0119 atomic percent, amounting to $183,213,717 \times 10^{16}$ atoms. The result is as follows:

$$\lambda_k = 0.585.10^{-10} \text{ year}^{-1}$$

$$\lambda_\beta = 4.68.10^{-10} \text{ year}^{-1}$$

$$\lambda_k/\lambda_\beta = 0.125$$

$$T = 1.317.10^9 \text{ years}$$

Substituting these values into the formula for K^{40} decay, we obtain

$$t = \frac{\log\left(\frac{Ar^{40}}{K^{40}}\, 9.00 + 1\right)}{2.2866} \text{ years}$$

or

$$t = 4.37.10^9 \log\left(\frac{Ar^{40}}{K^{40}}\, 9.00 + 1\right) \text{years}$$

The age so computed is 2.65% greater than that obtained with $\lambda_k = 0.6 \times 10^{-10}$ year $^{-1}$ and $\lambda_\beta = 4.9 \times 10^{-10}$ year $^{-1}$.

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APPLICATION OF STAINING TO POTASSIUM[2]

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In studying fine-grained acid extrusives and sub-extrusive rocks, investigators often come up against the difficulty of determining the nature of feldspars and especially the quantitative ratio of minerals in such rocks. Of considerable help in that operation is the method of staining K-feldspars in thin section, applied by the author and other petrographers in the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, AS U.S.S.R.

This method, worked out in 1929 by A. Gabriel and E.A. Cox [1], has been widely used for 20 years by petrographers of the U.S. Geological Survey. It is seldom mentioned in Russian geologic literature, although it deserves the widest recognition because of its simplicity and reliability.

The gist of the method is that free potassium is liberated in processing a mineral surface by HF vapors. A subsequent treatment of the mineral by $Na_3Co\,[(NO_2)_6]$, brings out a vivid lemon-yellow coloring of the surface of the K-bearing mineral. This method can be used on powdered samples of rocks carrying K-feldspar, on polished sections, and open thin sections. The dye is at hand in many chemical laboratories where it is used in the determination of alkalies. It can be prepared as follows: 30 gm of cobalt nitrate ($Co(NO_3)_2 \cdot 6H_2O$) are dissolved in 60 ml of distilled water: 50 gm sodium nitrate $NaNO_2$ are dissolved in 100 ml of distilled water. 10 to 15 ml glacial acetic acid are added to the mixture of the two solutions. The reagent so obtained is kept in a dark vessel, in a draft. It can be used 1 to 2 days after the preparation.

The staining proceeds as follows. Previously prepared open thin sections of rocks to be analysed are placed, face down, on the walls of a narrow lead, plastic or porcelain bath with HF at room temperature.

The etching by HF vapors is carried on for 1 to 4 minutes, depending on the room temperature and the nature of K-feldspars in the rock. S. Rosenblum [2] recommends cutting the etching time down to 15 to 20 seconds, in the belief that the color intensity depends in the main on the duration of the staining rather than of the etching. The section should be perfectly dry, to avoid the formation of acid on its surface through solution of the acid vapors in droplets of water, thereby producing an uneven etching. If the operation is performed with

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[2]Ob opyte primeneniya metoda okrashivaniya kaliyevykh polevykh shpatov.

hot HF vapors, the section should first be warmed up to the same temperature in order to reduce to a minimum the condensation of vapor. The etching is discontinued when a light white bloom has appeared on the section.

After that, the section is transferred to a flat bath with the dye. A very intensive coloring is achieved in 2 to 4 minutes. The dye is maintained at room temperature or below, because the slower the reaction, the more even the coloring.

According to F. Chayes [3], a longer staining process is required for Na-rich crypto-perthite K-feldspars and phenocrysts of some extrusive rocks. They should remain in the dye for 10 to 15 minutes.

After staining, K-feldspars take on a vivid lemon-yellow color. The staining does not affect their optical properties (index of refraction, extinction). Altered biotite takes on a weak coloring. Other minerals are not affected.

The author has stained fine-grained felsites, keratophyre, aplite, rocks with a micrographic texture, microcline-perthite, gneiss, and normal granite.

The staining highlights both the amount of K-feldspar in a rock and the details of its texture, such as the replacement segments, its presence in fine and intricate micropegmatitic growths with quartz and plagioclase, the presence of K-feldspar in an allotriomorphic substance which cements plagioclase microlites in the groundmass of some extrusives. The morphology of perthitic growths in microcline and hidden banding (as in some fine-grained aplitic granites of the Far East) is brough out quite well.

Given below are some examples of results obtained.

Thin section 446. Granophyre from the Svetlyy deposit. Porphyritic rocks with phenocrysts of isolated tabular grains and growths of feldspar crystals. The phenocryst feldspars are strongly clouded, with or without polysynthetic twins. Groundmass fine-grained, micrographic. Rounded "columns," up to 0.1 mm across, are formed by fine (0.01 mm) quartz bodies with a simultaneous extinction, interspersed with still finer bodies of cloudy feldspar. In addition, fine (0.05 to 0.1 mm) tablets of non-twinned feldspar are present in the groundmass.

The staining of this section has shown that both the porphyritic phenocrysts and the fine isomorphic tablets in the groundmass are formed by plagioclase albite (unstained). K-feldspar is present here in considerable amount as fine growths with quartz in a granophyre groundmass. In addition, it fills up the interstices between individual granophyre "columns."

Judging from the distribution of stained areas, the total K-feldspar content in the groundmass is 30 to 40%.

A flame photometric analysis of the granophyre groundmass for K and Na indicated 3.52% for the first and 2.56% for the second.

Thin section 236. Streamlined liparite. A vitreous rock with flow structure expressed in an alternation of fine bands of non-polarizing glass and of bands and lenses of glass with microfelsitic to pseudospherulitic crystallization, flowing about larger lenses with a greater number of quartz inclusions in a microfelsitic groundmass. The width of individual bands ranges from 0.02 to 2 mm. There are occasional phenocrysts of cloudy feldspar.

The staining has brought out the considerable content and uneven distribution of K-feldspar. The best crystallized bands and lenses are either free of it or else carry it in fine intercalations between the spherulite and felsite bands. The phenocrysts are plagioclase. K-feldspar is concentrated in most vitreous segments forming a series of fine, broken, and sinuous bands.

A similar picture has been observed in streamlined cement of acid tuffs (section 222), which suggests that K-feldspar was precipitated at terminal stages of the glass-crystallization process.

Thin section 527. Fine-grained slightly porphyritic aplite. Phenocrysts are rare tablets of feldspar and biotite. Groundmass panallotriomorphic-granular (grains 0.1 mm and less), consisting of quartz, feldspar, and subordinate biotite. The feldspars in the groundmass are strongly pelitic; plagioclase is mostly non-twinned. Fine parallel bands reminiscent of alteration zones are quite discernible to the naked eye; however, they are not discernible under the microscope.

In the staining, K-feldspars stood out sharply against the fine-grained groundmass, so that there was no difficulty in figuring out their percent content. The parallel bands turned out to be recrystallization zones almost fully of K-feldspar and somewhat coarser-grained (0.2 to 0.3 mm) than in the groundmass.

Our experience with this method of American geologists for staining K-feldspars in thin section has convinced us of its efficience and convenience. Even for well-crystallized rocks, the staining of a thin section simplifies and refines their quantitative mineralogic analysis, affords the observation of finer structural details in perthitic growths, replacement

segments, micropegmatitic intergrowths, etc. The staining of K-feldspars is especially helpful in work with fine-grained to crypto-crystalline rocks and with those where feldspars are strongly clouded. This is because this method not only establishes the presence or lack of K-feldspar in a rock but also the amount and form of occurrence.

The purpose of this communication is to draw the attention of petrographers to this method. It is very simple; in some studies it will greatly expedite the time-consuming work of rock identification.

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TO THE MEMORY OF LEV BORISOVICH RUKHIN[1]

In September of 1959, Lev Borisovich Rukhin, Doctor of Geologic and Mineralogic Sciences and Professor of General Geology at the A. A. Zhdanov Leningrad State University, passed away in his 47th year. This outstanding scientist, gifted teacher, and remarkable man is no longer with us.

L. B. Rukhin was born October 29, 1912, in Moscow; his father was an engineer. Early bereft of his father, he began his working life at the age of 13.

In 1928 he entered the Topographical Technicum; upon graduation, in 1931, he continued his education in the Geologic-Pedologic-Geographic Department of the LGU. By combining his study with work in the Salt Laboratory of the AS U. S. S. R., L. B. Rukhin graduated after two years, majoring in two fields: Geography (geomorphology branch) and Geology (paleontology). That was the period of his first scientific work on sulfates of the Aral region and mineral springs of the Far East.

In 1934, he became a graduate student in paleontology and one year later he successfully defended his Candidate's thesis on "Upper Silurian Tabulata of the Turkestan Range and Khan-Tengri." Paleontology was his main interest, at that time. He published a number of works on Silurian and Devonian Tabulata of Central Asia and Kazakhstan, Lower Devonian Favosites of the Trans-Baykal region, corals and stromtoporoids of the Kolyma lower Paleozoic, and Paleogene mollusks of the Aral region. These early works demonstrated his outstanding ability.

From 1935 on, L. B. Rukhin taught general geology at Leningrad University. During the summer field work with his students in the Leningrad area, he became interested in the conditions of formation of Cambrian and Silurian deposits in the Leningradskaya Oblast'. From then on, the problems of lithology and paleogeography became his main interest.

His study of Cambrian and Silurian deposits led him to the concept of the critical role of tectonic movements in the distribution of sediments. He developed this idea to the end of his days. It has found its fullest expression in his Principles of Lithology and in his last work, Principles of General Paleogeography.

Early in his work on lithology. L. B. Rukhin worked out and proposed a new method for determination of the deposition conditions of ancient sands, based on the study of their granulometric composition. This method has gained rapid recognition; it is being used by lithologists both in this country and abroad.

In his work on the problems of the granulometric composition of sandy rocks, he promoted precise and objective statistical methods for processing granulometric data and successfully applied them to the understanding of the origin of sedimentary rocks.

In 1940, L. B. Rukhin joined the C. P. S. U. In the same year he finished his Doctor's thesis of Granulometry and the Origin of Sands.

During the Great Patriotic War he participated in the defense of Leningrad in the ranks of the People's Militia.

In 1943 L. B. Rukhin defended his Doctor's thesis in the I. M. Gubkin Moscow Petroleum Institute and published a number of works on granulometry and the origin of sand sections.

From 1947 to 1953 he worked on his capital compendium, Principles of Lithology, published in 1953. This book has gained high esteem both in the Soviet Union and abroad. It was translated into Chinese, French, and German (it was published in France in 1956, in the Chinese People's Republic in 1958, and a rewritten edition of it was published in the German Democratic Republic in 1958).

This work, a result of many years of

[1] Pamyati L'va Borisovicha Rukhina.

scientific and teaching experience, presents not only a description of sedimentary rocks but a systematic exposition of the principles of lithology as an independent discipline, including a theory of facies and formations. The Principles of Lithology offers a systematic and original description of field and office methods of facies analysis and suggests means of study of the origin of ancient sedimentary rocks and their groups.

In 1951 L.B. Rukhin began his study of stratigraphy, lithology, and the conditions of formation of Cretaceous deposits in Central Asia, in connection with their oil and gas prospects. He correlated individual types of Cretaceous sections and worked out a single classification for the entire Fergana, which had eluded previous investigators. At the same time, he demonstrated remarkable examples of paleogeographic analysis and forecasting in the search for oil.

In 1959 his main work appeared, Principles of General Paleontology, which is a logical follow-up to his Principles of Lithology, presenting a systematic exposition of the methods of paleogeographic analysis and the making of paleogeographic maps, along with the history of development of ancient landscapes of the earth and their dependence on tectonic processes.

Recently, L.B. Rukhin was planning a book on regularities in the distribution of facies and formations over the earth, in various geologic periods.

During his 24 years at Leningrad University, he taught general geology, tectonics, lithology, theory of facies, and paleogeography. From 1945 to 1948 he was Dean and then Assistant President (Prorector) on Academic Affairs, of the A.A. Shdanov Leningrad State University.

Along with his extensive scientific and teaching work, L.B. Rukhin was socially active as a member of the Party Bureau for the Geology Department at LSU and Leader of the Student Scientific Society at the University.

He maintained close connections with various geologic organizations (VSEGEI, VNIGRI, NIIGA, Sredazneft', etc.), as a permanent consultant; he also was a member of the Commission on Sedimentary Rocks at the Section of Geologic-Geographic Sciences AS U.S.S.R., and actively participated in many All-Union lithologic conferences.

L.B. Rukhin has made a large contribution to the development of a new approach to lithology, on the basis of a genetic study of sedimentary rocks.

He was a shining example of a pioneer scientist who charted new ways of science, a brilliant scientific leader and teacher with a supreme love for science and his country; he has given them all of his ability and strength.

The bright memory of Lev Borisovich will always live in our hearts.

Collective of the Section of General Geology at the A.A. Zhdanov Leningrad State University

REVIEWS AND DISCUSSIONS

ON THE ORIGIN OF ANORTHOSITE AND TITANIUM MINERALIZATION[1,2]

by

A. P. Lebedev

The problem of the origin of anorthosite and of the existence and origin of an anorthosite magma remains as controversial as ever before in modern petrographic literature, and is open to different interpretations. Our interest in it is practical as well as theoretical because titanium mineralization is undoubtedly and closely connected with some anorthosite plutonic bodies.

The interesting and instructive book of I. I. Malyshev, summarizing the data on the original and placer deposits of titanium ores, also cites those deposits related to anorthosite, along with a discussion of the origin of such formations.

His fairly detailed study of these problems leads I. I. Malyshev to a number of conclusions of a fundamental character inasmuch as they bear not only on the solution of genetic problems but on a rational direction of exploration for titanium.

In view of the importance of these conclusions, and because I. I. Malyshev, in his discussion of individual topics, arrives at conclusions on the geologic position and origin of anorthosites, at variance with those set forth in my special paper [2], I deem it necessary to look closer into some of his premises.

On of the main problems of anorthosite is whether anorthosites are always of the same origin or whether there are different ways of their coming into being, i. e., are they heterogenetic or polygenetic.

An answer to this question calls first of all for a detailed comparative analysis of geologic conditions of occurrence of such formations in various regions. As has been shown in detail in my work [2], such an analysis unavoidably points to the heterogenetic nature of these formations, i. e., to the existence of anorthosites which have originated either from differentiation of a gabbroid magma or else from the independent palingenetic anorthosite magma. Finally their origin could have been metasomatic.

I. I. Malyshev himself admits (p. 104) that anorthosite plutonic bodies and formations differ greatly in their geologic position, dimensions, structure, relation to enclosing rocks and gabbroids, etc. All this, however, leads him to a surprising conclusion that all these rocks and their formations have originated in the same way, from a differentiation of gabbroid bodies. In so doing, he explains away, or rather leaves unexplained, those fundamental differences which indeed exist in nature between various types of anorthosite massifs and formations and which have been brought up, time and again, in the literature. First of all, there is the difference between large autonomous anorthosite massifs almost free of gabbroid components and titanium mineralization, on one hand, and anorthosite bodies which represent obvious schizoliths of large gabbroid complexes, often with typical titanium mineralization. Glossing over all these specific features and differences, brought forth by the painstaking efforts of generations of geologists, leads to unnecessary generalizations in the interpretation of a truly complex natural phenomenon. After having voiced his doubts as to differences in the formation of anorthosites and associated titanium mineralization, I. I. Malyshev further arrives at a categorical denial of any anorthosite magma in general. It appears that in so doing, I. I. Malyshev disregards the numerous field data suggesting the possibility and even probability, at some stage in the evolution of an intrusive body or deep igneous hearth, of a plagioclase melt, in the form of a very viscous mass with crystals

[1] K voprosu o genezise anortozitov i titanovogo orudeneniya.

[2] Observations on I. I. Malyshev's book, Regularities in the Formation and Distribution of Titanium Ore Deposits. Gosgeolizdat, 1957.

suspended in it. We are reminded here of the flow and trachytoid textures, the decrease in grain size in contact zones of anorthosite intrusive contacts, injections and veins having an anorthoclase composition, i.e., of all facts suggesting the formation of anorthosites from an independent magmatic melt.

To be sure, a solution of the problem of the primary nature of an anorthosite (plagioclase) magma presents great difficulties. The existence of such a melt appears to be contradicted by experimental data which suggest the necessity of very high temperatures for the fusing of a basic plagioclase (under laboratory conditions), also by the absence of extrusive anorthosite analogues, etc. At the same time, it must not be forgotten that we are far from having an adequate concept of the existence and equilibrium conditions for a similar melt at great depths and pressures, as pointed out in the literature, recently. Even the concept of a dough-like plagioclase melt, an aggregate of "squeezed" or "buoyed up" plagioclase crystals, implies its existence in an almost liquid state at some previous stage of its evolution. Otherwise the mechanism of movement through the crust, the formation of veins, apophyses, small injections, etc., becomes incomprehensible.

In denying all possibility of existence of an anorthosite melt, and consequently of a development of contact and assimilation phenomena at its contact with host rocks, we thereby disregard all incontrovertible facts of the reworking of basic xenoliths, observed in a number of anorthosite massifs. These facts, implying, of course, metasomatic processes, are not taken into account in I.I. Malyshev's deliberations.

I.I. Malyshev takes vigorous, and I must admit generally well-taken exception to my assumption of a genetic connection between anorthosites of some formations and granitoid magmas (p. 107). However, while fully agreeing with I.I. Malyshev as to the hypothetical nature and the lack of argumentation for my views (which I mention in my paper), I cannot pass by the same inadequate argumentation for the opposite view, i.e., of a mandatory connection between anorthosite and a gabbroid magma. It seems that such a treatment of this problem is too cavalier. The literature is full of references to the possibility of the formation of anorthositic rocks (basic to intermediate plagioclase) also from a granitoid magma, precisely in its interaction with calcium-rich rocks.[3] To be sure, the best evidence of such reactions would be an experimental one; even so, the possibility of genetic relationship of anorthosites and an acid to intermediate magma cannot be overlooked, along with other possibilities.

Having rejected both the magmatic (i.e., from a special anorthosite magma) and the other origins (such as metasomatic) for anorthosite, I.I. Malyshev is left with the concept of anorthosites solely as differentiates of a gabbroic or basaltic magma (p. 109). In that position, he does not consider either the concrete mechanism of such differentiation or the formation of large autonomous massifs free of gabbroid and ultrabasic components.

As we mentioned before, such a categorical conclusion is in contradiction to the variety of relationships actually observed in nature. First of all, there is a great variety of quantitative ratios of gabbroid to anorthosite members of intrusive complexes; second, there are variations in lateral and age relationships; finally, vein and ore differentiates differ greatly in composition and position. It is a study of these specific examples that establishes general regularities in their structure and petrogenesis, and brings out the genetic differences between their components. By disregarding actual natural relationships, we find ourselves without means of explaining the diversity of natural phenomena; specifically, we are at a loss for a comprehensive approach to the problem of the origin of titanium mineralization itself; in other words, at a loss for an explanation of the sharp differences in titanium content in individual massifs and formations, and consequently for an adequate forecasting criterion.

In explaining the formation of titanium deposits and the appearance of ultrabasic components in anorthosite and gabbroid formations, I.I. Malyshev advances the concept of a basic rather than acid residual fluid accumulating in a basalt magma during its progressive differentiation.

As to whether such a regularity (the accumulation of an ultrabasic residue) is operative in all or only a few stages of evolution of a basalt melt, and how it bears on the normal course of differentiation where the accumulation of an acid residue occurs, is not mentioned by I.I. Malyshev. Without pausing for a more detailed treatment of this topic, we note only that he oversimplifies a problem as complex as the origin of ultrabasic rocks and titanium ores by not considering the differences in natural processes. It should be kept in mind that even the processes of accumulation and concentration of titanomagnetite in a basic magma may run quite different courses, depending, for example, on the dept of solidification, as recently and convincingly demonstrated by K.O. Kratz [1] in his study on a three-component system, silicate-magnetite-volatile.

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[3]As witness trondjemite and plagioclasite, obviously related to rocks of the granodiorite and granosyenite series, in many regions.

Thus the attempt to explain everything from a single concept of differentiation, regardless of how well it fits a given geologic situation, leads I.I. Malyshev, in his solution of the problem of the origin of anorthosite and its titanium mineralization, to the conclusion that, in effect, any anorthosite as well as any gabbroid carries the same promise of titanium mineralization. This is a petrologic "criterion" ad absurdum; as such, it loses all meaning.

Voluminous and diversified material on igneoug titanium ore deposits, which is set forth in I.I. Malyshevs book, is still waiting for a genetic interpretation, in many respects.

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A REPLY TO M.K. KHUDOLEY ON MY BOOK, "MESOZOIC AND TERTIARY DEPOSITS OF THE BAYKAL AND TRANS-BAYKAL REGIONS AND THE FAR EAST."[4,5]

by

S.G. Sarkisyan

Izvestiya of the Academy of Sciences, U.S.S.R., Geologic Series, no. 3, 1959, carried a review of my book, Mesozoic and Tertiary Deposits of the Baykal and Trans-Baykal Regions and the Far East. It notes three main shortcomings in my work: the incomplete use of material, errors in presenting actual data, and errata.

The main object of criticism was my description of the heretofore least-mentioned Jurassic deposits of the Far East. I am taxed with an incomplete presentation of the published material, including the proceedings of the Conference on Unified Classifications of the Far East, held in May, 1956.

My purpose was to clarify the petrographic and mineral composition of Mesozoic and Tertiary deposits in the known areas of Baykal Trans-Baykal, and the Far East. A description of their stratigraphy was not the subject of my study and I used only classifications by various authors, published between 1950 and 1955.

Thus, a book which went to press at the beginning of 1956 could contain only material prior to that year, but not that brought up at the 1956 conference, let alone the resolutions of that conference published at the end of 1958. Only the works of M.V. Korzh and N.N. Sokolova, published from 1956 to 1958 but familiar to me from the period of their writing, were included in the bibliography, prior to publication.

M.K. Khudoley proposes a new stratigraphic classification for Jurassic deposits of the Sikhote-Alin', including the South Maritime Province (Primor'ye). Incidentally, it differs somewhat from the one published in the proceedings of the Commission. Obviously, I could not adhere to the 1959 classification in a book prepared for publication in 1956.

In view of the fact that pre-1956 classifications of Jurassic deposits are different from the new ones, and that differences in opinion prevailed as to the age of some units (discrepancies noted by M.K. Khudoley in the description of sections from different regions) are quite natural. Such discrepancies were not apparent in 1956.

The critic is right in picking up the many errata, including those in the description of fossils. However, M.K. Khudoley is quite wrong when he condemns the many stratigraphic tables on the basis of two obvious misprints on page 8 (in the type and not in the manuscript) where the Middle and Upper Jurassic are placed opposite Lower Cretaceous.

Finally, about the unjust remark of the critic on the alleged lack of indications of either land or sea on our Upper and Middle Jurassic map (Figure 16): this is not true. The map shows the zones of marine, lacustrine, fluvite-lacustrine, and marsh-lacustrine deposits, as well as the probable zones of their development. It goes without saying that the space about them is dry land.

If, in the opinion of M.K. Khudoley, my work on the petrographic and mineral composition of Mesozoic and Tertiary deposits of the Baykal and Trans-Baykal regions and the Far East has not filled the gap in the geology of that province, and as a petrographer I did not have that in mind, it is to be hoped that he will come out in the near future with a comprehensive work which would enrich our literature in this field.

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[4]Otvet M.K. Khudoleyu po povodu moyey knigi "Mezozoyskiye i tretichnyye otlozheniya Pribaykal'ya, Zabaykal'ya i Dal'nego Vostoka.

[5]Izd. AN S.S.S.R., 1958.

REVIEW OF R.P. TUZIKOV'S PAPER, "SOME GENETIC FEATURES OF THE URUP PYRITE DEPOSITS (NORTH CAUCASUS)."[6]

by

V.V. Sviridov

The Urup copper pyrite deposits belong to the greenstone Paleozoic belt extending along the north slope of the Greater Caucasus from the Elbrus to Fisht Mountain. Here, as on the eastern Uralian slope, the rock complex and associated mineralization belong to a spilite igneous formation (in the Yu. A. Bilibin nomenclature, [1]).

R.P. Tuzikov [8] has come to the conclusion that the Urup pyrite deposits were formed after regional metamorphism of the enclosing rocks. His main argument is the development of non-schistose dikes of diorite, quartz diorite, and lamprophyre, merely mineral-metamorphosed at the contact with ores: involving silification, chloritization, etc. In addition, fractions and similarly oriented chalcopyrite veins, "pre-ore thrusts" involving chalcopyrite are present in the dikes.

This is the basis for the author's interpretation of a post-dike origin of ore bodies. He appears to regard this as the main point of his paper. However, it is this very assertion of R.P. Tuzikov to which we object most emphatically.

We have identified two groups of dikes in the Urup ore area. One represents almost unaltered non-metamorphosed dikes in composition: quartz diorite, granite, plagiogranite, granosyenite, biotitic albite, minette, kersantite, and spessartite. They are distributed chiefly in the lower part of the Devonian section, in the porphyrite-phyllite barren subformation, seldom in the upper quartz-albitophyre-diabase subformation, and they are 3 to 30 m thick. Along the Vlasinchikha River, quartz diorites are exposed in two stock-like bodies (120 x 300 and 100 x 700 m) elongated parallel to the general northwest-trending anticlinal structure.

The second group, matamorphic, is represented by propylitic dike rocks of the granodiorite-diorite and spessartite type They occur mostly in the ore section (in quartz albitophyre and tuff) and among ore bodies; they are 0.2 to 1.5 m thick, occasionally as much as 8 m.

While secondary alterations are rare in the first group of dikes where they are associated with contacts with the enclosing rocks, and are expressed at times by cataclastic effects, calcitization, and silicification, so that the original rock can always be identified, alterations of rocks of the second group are so complete that only the rock type can be determined. The femic components in these dikes have been fully replaced by pale green clinochlorite; quartz and feldspar are often recrystallized to a felsitic substance. The rocks abound in calcite which makes them fizz with 10% hydrochloric acid.

Dikes of the second group are always more or less schistose, rarely massive in their central parts. The direction of their schistosity coincides with the ore banding. The contacts of the dike-ore bodies are usually even and sharp. Under the microscope, the near-contact ores are slightly brecciated, with a somewhat higher content of fine-grained quartz and squashed quartz-calcite bodies. Pyrite and hematite are present in small amounts in the dikes. The "pre-ore thrusts" are common in the ore bodies as well; they are filled with a cryptocrystalline chalcopyrite.

The contact zones of strongly schistose dikes carry branching pyrite-chalcopyrite veinlets, not over 10 mm thick, and parallel to the contact. This means that the "pre-ore" fractures affect the ore bodies, also. We believe the metamorphosed dikes to be intra-ore (intramineralized dikes), with their time of formation very close but subsequent to that of the ores. No direct evidence of a replacement of dikes by ores has been observed.

It is most probable that chalcopyrite and other minerals were deposited in fractures during their migration from ores in the process of metamorphism. Similar post-ore dikes are described from the Urals by V.A. Zavaritskiy [4], I.S. Vakhromeyev [2], G.F. Chervyakovskiy [9], and V.P. Loginov [6].

In the section on "Age of the Ore Bodies with Relation to the Formation of Schistosity in Rocks," R.P. Tuzikov states that there are fragments of schistose rocks among the acid near-ore enclosing rocks. He believes that the formation of schistosity and a strong fractionization are possible prior to the metasomatic formation of ore bodies. We have studied in detail the ore-contact rocks (in mine shafts and boreholes) and we did not observe anything to warrant such assumptions. Silicious metashales gradually change to quartzitic rocks. Brecciation is present locally in the near-wall segments of the Urup ore bodies, but it is obviously post-ore. Such breccias contain younger deposits of quartz, calcite, and less commonly albite and pyrite; however in places they do show a slight cataclastic effect.

[6] Po povodu stat'i R.P. Tuzikova 'Nekotoryye cherty genezisa urupskikh kolchedannykh mestorozhdeniy (Severnyy Kavkaz)."

In his Figure 4 on page 106, R.P. Tuzikov presents what appears to be the photograph of a core where an ore vein, conformable with schistosity, cuts a quartz vein cutting across the schistosity. Inasmuch as the ore vein displaces the quartz vein, which is young in relation to the rock schistosity, it is even younger. The photo shows that the contact lines of the quartz vein are uneven and that it is wedging out. In the ore sites, such veins are metamorphosed; we believe that they belong to the Alpine type. On the whole, comparatively fresh hydrothermal veins of an albite (oligoclase) - calcite-quartz composition are comparatively rare and marked by their consistency and even contact lines.

It may be assumed then that both the quartz veins and enclosing rocks have been metamorphosed; in consequence, the idea of the veins being younger than the schistosity loses all meaning. We, too, have observed veins cutting the schistosity of enclosing rocks, but they are thin, 1 to 3 cm on the average. This is also seen in R.P. Tuzikov's photograph. It is hardly correct to correlate the formation process of these veins with the large ore bodies. A.N. Zavaritskiy [4] and some other students believe such ore veins to be metamorphic.

R.P. Tuzikov's descriptions of and conclusions on the nature of the ore banding and pyritization suggest that he has neglected the microscopic study which has led us to the following conclusions:

First, tuffites themselves rather than siliceous metashales interbedded with them have been chloritized, as a rule. Ores replace the siliceous shale to a small extent and are developed both in the opening fractures and as a replacement of tuffite, quartz albitophyre tuff, and extrusives.

The assertion of R.P. Tuzikov that the formation of copper and zinc varieties of pyrite ores is connected with the replacement of siliceous metashales is very doubtful. We believe, rather, that the recurrent opening of fractures during ore impulses took place at the contact with incompetent siliceous shale.

Second, the microgranoblastic quartz present in quartz albitophyre is not as much a product of recrystallization of their vitreous component as the result of quartz metasomatism. Indeed, it is possible to trace all transitions from a felsitic groundmass to the granoblastic one, through the change of quartz albitophyre to secondary quartzite where the original quartz is represented by elongated metamorphosed grains, up to 0.2 mm long.

Third, according to R.P. Tuzikov, pyrite in incrustation ores was developed by pushing apart the shear planes, without undergoing deformation. As a matter of fact, we have determined that in the Urup deposit pyrite of incrustation ores is always fractured and exceedingly abundant in columnar quartz which is developed under stress. Ores of the Vlasinchikha and Skalistoye deposits are somewhat different: the fracturing of pyrite is not as well expressed in the first one; it is quite inconspicuous in the second where the pyrite is usually isometric, with a pentagonal-dodecahedral to cubic habit.

Banding is better developed near the walls of an ore body than in the center where massive varieties may occur. A collomorphic pyrite texture is not uncommon in the Vlasnichikha deposit. We have an idea that all three Urup deposits (Urup, Skalistoye, Vlasnichikha) show genetic features of their own. The Urup is the most metamorphosed of the three. The main factors of regional metamorphosed of the three. The main factors of regional metamorphism (pressure and temperature) were active for a long period, both before and after the ore formation. The four formations stages identified for the Middle Urals pyrite deposits in the latest paper by V.P. Loginov [9] are similar to those of the Urup deposit.

R.P. Tuzikov's conclusion, "The age relationship of the metamorphic section which we have assigned to the Devonian is not adequately proven. An older age cannot be ruled out," (p. 112) is in contradiction to that of V.N. Robinson [7] who assigned the greenstone sedimentary-volcanic Urup section to the lower Middle Devonian, in analogy with adjacent areas. According to Yu. D. Bochkovoy (1954), too, it belongs to the middle Paleozoic.

Furthermore, R.N. Tuzikov does not cite the literature used; in particular, he omits the paper of N.V. Ivanov [5] who describes in adequate detail the composition of the Urup ore bodies and explains their origin more convincingly, in accordance with A.N. Zavaritskiy's ideas on the metamorphism of pyrite deposits.

To explain the genetic aspect of an ore deposit, especially a Paleozoic one which has undergone a long series of later orogenies, is far from being an easy undertaking. A more or less correct understanding of the origin of an ore deposit calls for a careful study of the general structural geologic conditions of the region and the petrography of enclosing and contact rocks and the ores themselves. The publication by an author of disconnected data on a deposit may seriously mislead the reader.

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CHRONICLE

FIRST ALL-UNION VOLCANOLOGIC CONFERENCE[1]

by

V.I. Vlodavets

The First All-Union Volcanologic Conference was held in Yerevan, from September 23 to October 2, 1959, with about 300 participants representing 86 geologic and allied organizations from most of the republics of the Soviet Union.

The Conference summed up the results of study of recent and ancient volcanism, volcanic provinces and formations, associated industrial minerals, the relationship between volcanism and tectonics, and some other topics specifically cosmic volcanism.

These subjects were discussed in 104 papers presented in the Conference and in many talks by the participants. Five one-day field trips were conducted to acquaint them with the volcanism of Armenia: 1) Pambak, 2) Ashtarak-Byurakan, 3) Artik, 4) Sevan-Kamo, and 5) Garni-Gegard.

The Conference was opened by the Chairman of the Organizing Committee, Academician I.G. Magak'yan of the Armenian S.S.R. Academy of Sciences who spoke on the task before the First Volcanologic Conference and on the future course of volcanologic study. This was followed by papers on the works on Armenian volcanism by A.N. Zavaritskiy (read by K.N. Paffenholtz) and F. Yu. Levinson-Lessing and P.I. Lebedev (by V.P. Petrov and Ye.K. Ustiyev).

Papers on The Problems of Study of Recent Volcanism in the U.S.S.R. were read by V.I. Vlodavets, G.S. Gorshkov, and S.I. Naboko (Laboratory of Volcanism, AS U.S.S.R.) and on The Problems of Paleovolcanologic Study In the U.S.S.R. by V.I. Vlodavets, A.P. Lebedev, and G.M. Gapeyeva (Interdepartmental Commission on Ancient Volcanism).

These communication stressed the problem of magma as fundamental in volcanologic studies, because of its relationship to the problem of volcanic energy, the change of thermal into kinetic energy.

It was also noted that volcanism and its role in the evolution of our planet should be studied in close connection with cosmic volcanism, primarily with relation to the earth-moon system. A comprehensive consideration of volcanism calls for a clarification of the relationship between solid, liquid, and gaseous substances in a magma, their formation and separation in a volcanic process, and the distribution of elements in all three phases. Of importance also is a study of the volatile components of a magma, the formation of hydrothermal solutions, volcanic heat and its utilization for power and heating purposes, the forecasting of eruptions, and regional volcanic differentiation.

Considering the wide distribution of ancient volcanic formations in the Soviet Union and their important role in the origin and areal distribution of industrial mineral deposits, the extension of paleovolcanologic study should be recognized as an important branch of Soviet geology.

It is necessary to reconstruct the history of volcanism and to establish regularities in its development by taking into account the structure, composition, mineralogy, and metamorphism of ancient volcanic formations, by regions, as well as the typical features of volcanism in platform, geosynclinal, continental, and oceanic provinces. Without that, regularities in the development of volcanism in the earth's crust are difficult to understand.

The problem of relationship between certain types of mineralization and volcanic rocks was considered in a paper by V.N. Kotlyar and M.A. Favorskiy who pointed out that the widely

[1] I-ye Vsesoyuznoye vulkanologicheskoye soveshchaniye.

distributed deposits associated with extrusive rocks and subordinate minor intrusions of various ages deserve special attention with respect to their conditions of formation and the regularities of their distribution and concentration.

G. S. Gorshkov and S. I. Naboko noted in their paper, Present Volcanism of the Kamchatka-Kurile Ridge, the relationship of volcanoes to certain faults. The speakers argued for their classification by morphologic type and nature of eruption and they described the geochemical features of lavas and their changes parallel to and across the trend of the ridge.

A number of papers dealt with the formation of pyroclastic material (V. I. Vlodavets), classification of some types of explosive eruptions (G. S. Gorshkov), the possible formation mechanism for some magmatic chambers (Ye. K. Markhinin), the distribution of temperatures about a cooling-off volcanic vent (Ye. A. Lyubimova), the possibility of pressure determination for volcanic vapors at depth and the thermal flow of Ebeko volcano (A. S. Nekhoroshev), the methodologic basis of study of magnetic anomalies in volcanic areas (V. A. Bernstein), and paleomagnetic study (G. A. Pospelova).

Papers by S. I. Naboko, K. K. Zelenov, and V. V. Ivanov dealt with present hydrotherms, a very important topic especially for the understanding of some aspects of ore making.

Genetic features of Quaternary and present volcanic deposits in the northern part of Kamchatka were presented in a paper by I. I. Gushchenko.

A paper by A. T. Aslanyan treated some problems of the theory of volcanism. According to the speaker, thermal energy of subcrustal magmatic bodies is released in the gravity compression of the earth. Lava flows from subcrustal regions is caused by thermal energy of the magma itself while volcanic explosions are the result of a rapid release of energy of exothermal reactions in a magmatic reservoir, and of electric discharges in deep fault zones, with the resulting release of thermal energy sufficient for an explosion. Volcanic activity as a gas lift phenomenon is a process accompanying gravity differentiation and compression of the earth.

Cosmic volcanism was discussed in papers by N. A. Kozyrev On the Existence of Volcanic Activity on the Moon; by S. K. Vsekhsvyatskiy, Comets, Problems of the Solar System and the Earth's Volcanism; and by A. V. Khabakov, Some Features of the Geologic Structure and the Main Stages of Development of the Moon. The last paper was accompanied by a large-scale map of the moon with the relative ages of lunar formations marked on it.

These papers aroused considerable interest. V. A. Ambartsumyan, President of the academy of Sciences, Armenian S. S. R., stated that ejection and scattering of erupted substances does take place in the universe. Accordingly, evidence of volcanism should be looked for in the solar system.

A. A. Vardanyants noted that cosmic bodies (stars and planets) cannot be in a state of equilibrium. They are rather peculiar "machines" where matter is concentrated, on one hand, and is being transformed and ejected, on the other. This is one of the manifestations of volcanism.

The problem of volcanic provinces and formations and of the associated industrial minerals was also discussed in the Conference.

Papers in this field treated both the general and specific features of volcanism, the Paleozoic and to some extent the more ancient: for the Russian platform (Z. G. Ushakova); the Ukraine (L. G. Bernadskaya); the Urals (O. A. Nestoyanova, A. A. Pronin, N. A. Rumyantseva, I. D. Sobolev, G. F. Chervyakovskiy); Kazakhstan (L. I. Blokhina, V. K. Zaravnyayeva, Ye. Ye. Miller, N. P. Rusakova, E. I. Tikhomirova, G. M. Fremd); south Tyan'-Shan' (R. B. Baratov); the Kuramin Range (I. M. Volovikova and O. P. Yeliseyeva); the Altay (L. I. Zvyagintsev, B. N. Lapin, Ye. B. Yakovleva); and Tuva (G. V. Pinus); Mesozoic Trans-Caucasus (R. N. Abdullayev, G. S. Dzopenidze, E. G. Malkhasyan); the Urals and Trans-Urals (K. P. Ivanov); the northern part of the Siberian platform (Ye. L. Butakova); the Far Northeast (F. R. Apeltsin, M. Gel'man, I. Ya. Nekrasov, I. M. Speranskaya, K. Ya. Springis); Sakhalin (Z. P. Potapova) and Chukotsk region (V. F. Belyy). For the Mesozoic-Cenozoic: the Carpathians (V. P. Kostyuk); Trans-Caucasus (Sh. A. Azizbekov, G. M. Zaridze, P. F. Sopko); and Kamchatka (M. M. Vasilevskiy and G. M. Vlasov). For the Cenozoic: Armenia (G. P. Bagdasaryan, A. S. Ostroumova); Greater Caucasus (Ye. Ye. Milanovskiy); north Caucasus (G. D. Afanas'yev and A. M. Borsuk); south Sakhalin (V. N. Shilov); and the Koryak Range (B. Kh. Yegiazarov and G. A. Zakrzhevskiy). For the Quaternary: Armenia (V. M. Amaryan, A. T. Aslanyan, K. I. Karapetyan, K. G. Shirinyan); the Elbrus (N. V. Koronovskiy), Kamchatka (E. N. Ehrlich), and the Datun group of the CPR (China) (V. I. Lebedinskiy). Of outstanding interest were papers of K. G. Shirinyan and Ye. Ye. Milanovskiy on the origin of tuff and tuffaceous lavas of Armenia and the Elbrus, illustrated with convincing examples of tuffaceous lavas formed as a result of the foaming up of a lava.

Industrial minerals associated with volcanic provinces were discussed in papers on the formation of pyrite deposits in Azerbaydzhan (M. A. Kashkay), nonmetals (V. P. Petrov),

ources of free silica (M.A. Petrova), and on in mineralization of the South Maritime Province (Primor'ye).

There was a paper by G.M. Gapeyeva on rincipal differences of volcanism in island rcs, continental coasts, and intracontinental rovinces; and by V.V. Zolotukhina on the letermination of the forms of occurrence for xtrusive rocks from the distribution of lagioclase in them.

Many papers dealt with Volcanism and Tectonics in Various Provinces of the Soviet Union, uch as the Soviet Carpathians (Ye.F. Maleyev); he Caucasus (K.N. Paffenholtz); Lesser Caucasus (A.A. Gabriyelyan, E.Sh. Shikhalibeyli); eorgia (N.I. Skhirtladze); Tyan'-Shan' (Ye.N. oretskaya); Tuva (T.N. Ivanova); the Siberian latform (V.A. Vakar and A.P. Lebedev, M.I. abkin and V.A. Milashev, Yu.M. Scheinnann); the Mongol-Okhotsk belt: (M.S. Nagiina), the Okhotsk belt (Ye.K. Ustiyev); the ar East (M.I. Itsikson and L.I. Krasnyy), nd the Komandor Islands (Yu.V. Zhegalov). here were two papers of a general nature: n igneous activity and tectonophysics (M.V. zovskiy) and volcanism, tectonics, and the roblems of actualism (A.Ye. Svyatlovskiy).

The concluding session was a symposium n classification, nomenclature, and termiology, with the emphasis on pyroclastic rocks, ne rock group which has been the subject of ively interest in recent years, because of its ewly acquired importance in geologic practice. he problem of classification and its principles ere discussed in a number of papers (V.I. lodavets, V.P. Petrov, Ye.F. Maleyev, V.S. optev-Dvornikov, L.I. Blokhina, M.G. Lomize, I.A. Petrova, E.I. Tikhomirova, T.I. Frolova nd Ye.B. Yakovleva, Ye.V. Bykovskaya, G.M. apeyeva, Ye.N. Goretskaya, M.L. Lur'ye, .M. Sergiyevskiy and M.V. Tashchinina; G. I. Fremd, I.M. Speranskaya, and L.G. Kvasha). he nomenclature of volcanic rocks was disussed by Yr.K. Ustiyev, Ye.F. Maleyeva, G. I. Fremd; I.M. Speranskaya, and L.G. Kvasha.

After a lively exchange of opinions, a comission of representatives from interested rganizations was elected to work out a clasification of volcanoclastic rocks. This comission is now at work.

The Conference took cognizance of the small umber of papers on major scientific problems nd on the lag of theoretical knowledge of deepeated processes, primarily volcanic phenomna, and associated processes of formation of ocks and ores.

It was brought up that not enough attention as paid by the Conference to hydrothermal henomena related to volcanism, as a whole, or to the problems of geothermy, the relation of mineralization to subvolcanic extrusive rocks, and to pyrite deposits. Also brought up were the small number of absolute-age determinations, the gap between the study of present and paleovolcanism, and the need for a number of experimental works in these fields.

The Conference adopted a resolution stressing the importance of study of volcanism for knowledge of the earth and cosmic space. Such a study is important also for the needs of state economy. The foremost problems have been listed as follows:

1. A broadening and deepening of the study of recent and latest volcanism, inasmuch as such study is the basis and source of understanding of ancient volcanism and the origin of associated industrial minerals.

2. A study of volcanic formations in the U.S.S.R., and of regularities in the distribution of industrial minerals associated with volcanism. The goal of such a study should be a reconstruction of the history of ancient volcanism and the preparation of paleovolcanic maps for main structural elements of the earth's crust: platforms, ancient geosynclines, island arcs, etc.

3. A clarification of the relationship between volcanic and plutonic formations and between volcanism and tectonics.

4. A development in theoretical petrography and geophysics, especially as regards the origin and evolution of magma.

5. An intensification of the study of volcanic metallogeny in geosynclinal and platform provinces.

6. A study of the structure of the earth's crust in the areas of present and recent volcanic activity.

7. A broadening of geochemical and geothermal study in the provinces of present and very recent volcanism.

8. An intensification in the work of forecasting volcanic eruptions and of special volcanic classification of the land areas in order to warn the population of impending danger.

9. A strengthening of special model studies of natural processes, directed toward a description of the physical properties of matter at higher temperatures and pressures.

10. A development of study of cosmic volcanism in the solar system.

It has also been noted that a successful solution of these problems necessitates certain

methods of study and organizational measures, such as a technically equipped volcanologic service of the U. S. S. R., and scientific volcanologic laboratories, sections, or groups at the Union, Azerbaydzhan, Armenian, Georgian, and Ukrainian Academies of Sciences, the institutions of the Ministry of Geology and the Conservation of Mineral Resources of the U. S. S. R., a number of the Academy's Affiliates, and local geologic administrations.

It was resolved to hold annual symposia on the problems of volcanology. The Second All-Union Conference on Volcanology was scheduled at Petropavlovsk-on-Kamchatka, with field trips to the areas of active volcanoes and hot springs.

In conclusion, the great work by the Academy of Science of the Armenian S. S. R. should be commended, on the organization and conduct of the Conference and the field trips, and on the publication of expanded abstracts which came to a voluminous (about 500 pages) and interesting book, Problems of Volcanism, and of a Field Trip Guide, with maps and photographs.